RIVERS STATE UNIVERSITY
PORT HARCOURT

UNIT OPERATIONS APPLICATION IN THE DEVELOPMENT OF LOCAL CONTENT: A KEY TO NIGERIAN ECONOMIC GROWTH

AN INAUGURAL LECTURE

BY

PROFESSOR
FALILAT TAIWO ADEMILUYI
B. Sc Chemical Engineering (Unilag), M. Tech,
PhD (Chemical Engineering) (RSUST) MNSE, FNSCHE

Professor of Unit Operations In Chemical Engineering
Department of Chemical/Petrochemical Engineering, Faculty of Engineering

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DEDICATION

This inaugural lecture is dedicated to the Almighty God, my Everything and my All. My Lord and Saviour Jesus Christ and the Holy Ghost, author of all my Inspirations,

Loving memory of my parent Late Chief Olukayode Kamorudeen Adegboyega and Late Deaconess Nike Adegboyega

and

My God-sent Loving Husband Prince Ademola Thomas Ademiluyi and my three Lovely Children, Prince Toluwani Ademiluyi, and Princess Tofunmi Ademiluyi and, Prince Oluwatobi Ademiluyi

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PROTOCOL

Chairman of the Governing Council
The Vice-Chancellor and Chairman of this occasion
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The Registrar and Secretary to Council and Senate
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Deans of Faculties and Directors of Institutes and Centres
Heads of Departments and Units
Distinguished Professors and Members of Senate
Academic, Administrative and Technical Staff
Graduate and Undergraduate Students
Ministers of God
Your Royal Majesties and Highnesses
Members of the Fourth Estate of Realm
All Invited Dignitaries,
Distinguished Ladies and Gentlemen.

PREAMBLE

Vice Chancellor Sir, am grateful to God Almighty who made it possible for me to present the 93rd inaugural lectures today. I recall Sir, you were the first to congratulate me in 2018 at Postgraduate School when you were Dean on my promotion to Professor almost one year after my appraisal by AP & C which was then backdated to July 2017. Thank you, Sir, for all your concern and love to all your staff, indigene or non indigene.

My Journey to Port Harcourt

I completed my National Youth Service Corp (NYSC) in 1992 at the Federal University of Technology Owerri, and I started praying and seeking the face of God to know where I should go after my service year. After some days, I heard a voice …to go to Port Harcourt. Therefore, instead of returning to Lagos. I quickly left Owerri for Port Harcourt to stay with my Late uncle Chief Adegbuyi Adekoya who secured a job for me with Spibat Nigeria Limited where I started working as a draughtsman preparing bar bending schedule for site work at the Eleme petrochemical plant.

While at Spibat, I honestly wanted something that would task my brain so I was not satisfied with my monotonous job. I therefore applied for my master's at the University of Lagos

(UNILAG) while working there and was offered admission. After praying about it, I found out that God was not leading me back to UNILAG even though I had a first-class there. I then remembered that I saw an exhibition of products from Rivers State University of Science and Technology on NTA, so I tried to locate where the university was since I was in Port Harcourt.

On getting to Rivers State University, I went to the Department of Chemical/Petrochemical Engineering and met the then Head of the Department Professor E. N Wami. I showed him my Master's admission letter from UNILAG and I informed him that I had a First Class in Chemical Engineering but didn't want to go back and that I wanted to do it here. He stood up and took me to Postgraduate School where we met the Deputy registrar. I was given a form, and I immediately filled it and submitted all my credentials, which was processed without delay and I got my admission letter, that was how I became a postgraduate student of River State University in 1993. I completed my Masters of Technology degree in Chemical Engineering with a CGPA of 4.76.

My Journey into Academics

I had been praying to God concerning marriage while I was at Owerri during my Youth Service and God told me that I would see my husband on campus. He answered that prayer and I got married to Pastor Dr Jacob Alabi in 1995 who was a Senior Lecturer in the Department of Mechanical Engineering at Rivers State University of Science and Technology. Sadly, I lost him after a brief illness that same year after the wedding which was held in Lagos. I left Rivers State University of Science and Technology and went back to my uncle's place in Port Harcourt not knowing what tomorrow holds for me, but later got a job and started working as a Chemistry teacher at Bereton International Secondary School, Port Harcourt . There, I had another dream and God showed me people suffering in RSUST and I was going away not willing to do anything about it or help the people around me. After this dream, I knew the death of my late husband will not stop my career at RSUST.

Therefore, I went back to see my former HOD and shared with him my intention to work at RSUST. My HOD, Dr. S. E Ovuru was happy about my intention to come back and I quickly applied as a graduate assistant since that was the only slot available and which was gracefully approved by my Dean Late Prof K. I. Idoniboye and the then Vice-Chancellor, Prof Steve Odi-Owei in January 1997, since I had a first-class and one of the best students in masters class pending senate approval of my master's results in October 1997. I left my new job as a secondary school chemistry teacher earning over ₦5000 and took a job as a Graduate Assistant to earn ₦3000 plus. I didn't mind because I knew God wanted me to be here.

I then applied for the Commonwealth Scholarship and was nominated for the scholarship, but because of the long ASUU strike, it was difficult to get my transcript and send it to the United Kingdom, which caused six of us to lose our nominations in the country after the strike that year. I went back to God again and He said I should do my Ph.D. here and that I should continue the Cassava work I gave my former student in the department, (Now Prof C. P. Ukpaka).

I then enrolled for my Ph.D. in 1998 but was disrupted by the movement of my main supervisor outside the state on a federal assignment. I reapplied again in 2001 and was given new Ph.D. supervisors who by the grace of God supported me to complete my Ph.D in 2009. My Ph.D work on Cassava marks the beginning of my research on Local materials.

Three times I had made an attempt to leave the then-River State University of Science and Technology but the Lord would hold me back with a dream, after the third dream, I concluded that this was where God wanted me to be and I give God all the glory for these unmerited favors.

1. INTRODUCTION

Vice Chancellor Sir, today is a unique day in the History of this University and the Faculty of Engineering, as it marks the first inaugural lecture by the first female Professor of the Faculty of Engineering, Rivers State University. My area of specialization in Chemical Engineering is UNIT OPERATIONS and it would be interesting to know what Unit operations is all about before dealing with this topic.

1.1 What is Unit Operations?

Unit operation in chemical engineering is a basic step in a process. Unit operations involve a physical change or chemical transformation such as Distillation, Adsorption, Absorption, Drying, crystallization, evaporation, filtration, polymerization, isomerization, and other reactions. Many unit operations are required to obtain a desired product from the feedstock or raw materials used.

Unit operations in Chemical Engineering consist of five classes namely:

- Fluid flow processes: Fluid transportation, filtration, and solid fluidization.
- Heat transfer processes: Evaporation and heat exchanger.
- Mass transfer processes: Drying, gas absorption, extraction, and adsorption.

* Thermodynamic processes: Gas liquefaction and refrigeration.
* Mechanical processes: Solid transportation, crushing, pulverization, screening, and sieving.

Chemical Engineering unit operations also involve the following: (McCabe *et al.*, 2004):

* Combination (Mixing)
* Separation (Distillation, crystallization).
* Reaction (Chemical reaction)

Most of my research was in unit operations especially mass and heat transfer operations, specifically adsorption, absorption, mixing, drying, extraction, filtration, and Pyrolysis. My choice of this area of research was borne out of the search for transforming local materials into useful products as well as looking for alternative sources of energy other than fossil fuels for developing country like Nigeria.

1.2 Definition of Key Concept

a) Engineering

Engineering deals with the application of science to the optimum conversion of natural resources to a form useful to mankind. The scientist seeks to know, while that of the engineer seeks to do. Engineering principles are based on physics, chemistry, and mathematics and their extensions into materials science, solid and fluid mechanics, thermodynamics, transfer and rate processes, and systems analysis. Also, Scientists add to the store of verified systematized knowledge of the physical world, while engineers bring this knowledge to bear on practical problems.

Engineers employ two types of natural resources namely:

a. Materials that are useful because of their properties: their strength, ease of fabrication, lightness, or durability; their ability to insulate or conduct; their chemical, electrical, or acoustical properties.
b. Energy includes fossil fuels (coal, petroleum, gas), wind, sunlight, falling water, and nuclear fission.

Most useful resources are limited, engineers must concern themselves with the continual development of new resources as well as the efficient utilization of existing ones

b) **Chemical Engineering**

Is an aspect of engineering that deals with the development of economical commercial processes and, the design and operation of chemical plants to convert raw materials into useful products, unlike chemistry which investigates the science encompassing aspects of organic, inorganic, analytical, physical, and biochemistry of such raw materials.

c) **Use of Local Content**

This is the use of indigenous technology, materials, and skills in the development of raw materials into useful products that are from the area where the product is made instead of being imported.

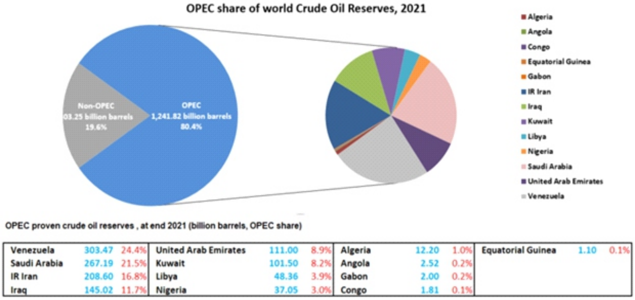
1.2.2 **Crude Oil Reserve in Nigeria**

Our reserve with time will not increase but decrease, we have 37.05 billion barrels in 2021 with OPEC (Fig 1). The Speaker of the House of Representatives, Hon. Tajudeen Abbas has said that the country lost about $46 billion (N16.25 trillion) to crude oil theft between 2009 and 2020. Adding that "Nigeria has continually failed to meet its daily production quota as set by the Organization of the Petroleum Exporting Countries (OPEC)."

Abbas explained further that "recently, Nigeria's OPEC quota was reduced from 1.742 million barrels per day to 1.38 million barrels per day. Yet, the country is still struggling to meet this quota as daily production output was 1.184 million barrels per day and 1.249 million barrels per day in May and June 2023 respectively (Vanguard 2023).

Vice Chancellor Sir, the need for Nigeria to diversify into other areas to sustain our economy in the future, led to my Engineering local materials using different Unit Operations in the following areas of research:

Drying b) Drilling c) Pyrolysis, d) Adsorption f) Absorption g) Extraction h) filtration



OPEC proven crude oil reserves , at end 2021 (billion barrels, OPEC share)

Venezuela	303.47	24.4%	United Arab Emirates	111.00	8.9%	Algeria	12.20	1.0%	Equatorial Guinea	1.10	0.1%
Saudi Arabia	267.19	21.5%	Kuwait	101.50	8.2%	Angola	2.52	0.2%			
IR Iran	208.60	16.8%	Libya	48.36	3.9%	Gabon	2.00	0.2%			
Iraq	145.02	11.7%	Nigeria	37.05	3.0%	Congo	1.81	0.1%			

Fig 1 OPEC Crude oil reserves at end 2021

Source: OPEC (2022)

Vice Chancellor Sir, the materials I had chosen for conversion using the Unit Operations and for other research over the years have been cassava and other waste materials in our environment such as Bamboo (after being used from construction sites), Palm kernel Shell, Palm bunch, Waste Avocado seed, Coconut Shell, Tallow seeds and shells, as well as waste water sachets. The first Unit operation, I researched was Drying using the Rotary dryer.

2. DRYING

One of the final steps in most unit operations involving solids is Drying. It is a mass transfer process consisting of the removal of water or another solvent by evaporation from a solid, semi-solid, or liquid (Green 1998). Most of my earlier research, especially my PhD work which was the development of predictive models for drying fermented ground cassava in a rotary dryer (Ademiluyi, 2009) was focused on this. Cassava was the major material used in most of the drying studies.

2.1 **Why Cassava?**

Cassava (Manihot esculenta) is a perennial woody shrub with an edible root, which grows in tropical and subtropical areas of the world. Cassava originated from tropical America and was first introduced into Africa in the Congo basin by the Portuguese around 1558. Today, cassava supports the livelihood of over 300 million Africans. It is rich in carbohydrates, calcium, vitamins B and C, and essential minerals. However, nutrient composition differs according to the variety and age of the harvested crop, and soil conditions, climate, and other environmental factors during cultivation. (IITA, 2005 & IITA, 2010). Nigeria produces more cassava than anywhere else in the world, followed by Thailand, Indonesia, and Brazil as shown in Table 1. The Nigeria Cassava Growers Association (NCGA) president estimated industrial items imported by Nigeria derived from cassava to be N1.2 trillion annually. He added that mass production of these derivatives could earn Nigeria over N10 trillion annually.

2.1.2 **Food and Non- Non-Food Uses of Cassava**

- Food industry: as a thickener, paste, or syrup for candies etc.

* Pharmaceutical industry: as a syrup for medicines, binders for tablets
* Cosmetics industry: as a paste for cosmetics
* Textile industry: as a sizing agent for textile
* Paper and furniture industry: as an adhesive and glue for papermaking

2.1.3 Cassava Structures/ Structures of Compounds in Crude Oil

Pure starch which is one of the byproducts of cassava is a white, tasteless, and odorless powder that is insoluble in cold water or alcohol (Fig 2a). It consists of two types of molecules: the linear and helical amylose and the branched amylopectin. Starch is a long chain of sugar molecules linked together. There are two forms of starch: amylose, the branchless form, and amylopectin, the branched form. The main function of starch is as a way to store energy for plants. Starch is a source of good sugar in human and animal diets.

Fig 2a Cassava harvested and peeled from one of our research farm on Campus

2.1.3 **Cassava Production Trend in the World/ Nigeria**

The production of cassava in the World grew substantially from 101 million to 314 million tonnes rising at an increasing annual rate that reached a maximum of 8.28% in 2006 and then decreased to 3.64% in 2021, between 1972 and 2021. Nigeria is producing the largest cassava in the world as shown in Table 1. There are over 100 varieties of cassava cultivars, for food and industrial uses. (IITA, 2010)

2.1.4 **Chemical Formula of Starch**

Starch is composed of glucose molecules; the basic formula of starch is very similar to that of glucose. However, to link together, glucose molecules have to lose some of their components. Specifically, starch is composed of sugar glucose. Glucose is a sugar molecule made up of carbon (C), hydrogen (H), and oxygen (O) with a basic chemical formula of $C_6H_{12}O_6$. Starch is a chain of glucose molecules, but the chain isn't always straight. Sometimes, the sugar molecules branch off from the main chain and form their own, just like a tree has a main trunk and then branches. As such, starch has two forms: one form has no branches while the other form does. The branchless form is amylose as shown in Fig 2b.

Table 1 Top Cassava Producing Countries in the World

Rank	Area	Production Value of Cassava (in tons) 2019	*Production Value of Cassava (in tons) 2021
1	Nigeria	47,406,770	63,031,376.66
2	Thailand	30.227,542	30,108,352
3	Indonesia	23,936,920	17,749,000
4	Brazil	21,484,218	18,098,115
5	Angola	16,411,674	9,866,553
6	Ghana	15,989,940	22,681,510.4
7	Democratic Republic of the Congo	14,611,911	45,673,454
8	Viet Nam	9,757,681	10,565,589.17

*Source: FAOSTAT (2019) & *KNOEMA (2021)*

Amylose can contain over 250 glucose units per molecule of amylose. Since it doesn't have branches, amylose can form a 3-D

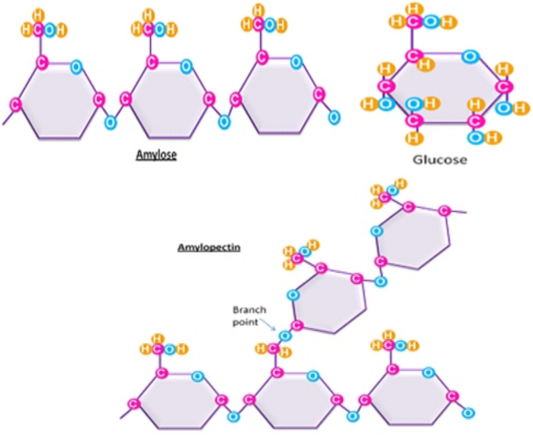


Fig 2b Structure of Starch (Amylopectin and Amylose)

helical structure, much like a slinky. It would be awkward to carry around and hard to store. The 'slinky' structure of amylose allows cells to store energy in a compact form but also makes it easily accessible.

Amylopectin is the branched form of starch and can contain over 1,000 glucose units. The main chain of hand-holding glucose is still there, so where does the branching-off glucose attach? It attaches to a different carbon, rather like a third person holding on to your belt while you hold hands with two other people.

Crude oil is a mixture of comparatively volatile liquid hydrocarbons (compounds composed mainly of hydrogen and carbon), though it also contains some nitrogen, sulfur, and oxygen. Those elements form a large variety of complex molecular structures, some of which cannot be readily identified. Regardless of variations, however, almost all crude oil ranges from 82 to 87 percent carbon by weight and 12 to 15 percent hydrogen by weight.

Crude oils are customarily characterized by the type of hydrocarbon compound that is most prevalent in them: paraffin, naphthene, and aromatics. Certain liquid paraffins are the major constituents of gasoline (petrol) and are therefore highly valued. Naphthene is an important part of all liquid refinery products, but it also forms some of the heavy asphalt-like residues of refinery processes. Aromatics generally constitute only a small percentage of most crudes. The most common aromatic in crude oil is benzene, a popular building block in the petrochemical industry, as shown in Fig 3.

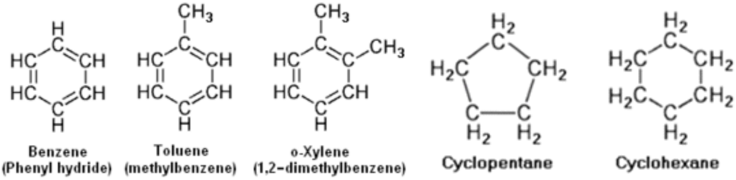


Fig 3 Structure of some compounds found in Crude oil

Vice Chancellor Sir, looking at the basic structures of starch and glucose and comparing them with that of compounds found in crude oil (Figs 2b and 3) as well as their composition in Tables 2 and 3, you can see that similar benzene rings are present which make cassava or any carbonaceous plant easy to convert to energy? Also, the C, H, N, S and other metals you see in crude oil are also present in cassava. This is why Nigeria can Engineer cassava in place of crude oil now and in the future.

Table 2 Crude Oil Composition

Element	**Weight % in Crude oil**
Carbon	83 to 87
Hydrogen	10 to 14
Nitrogen	0.1 to 2.0
Oxygen	0.1 to 0.5
Sulfur	0.5 to 6.0
Metals	Less than 1000 ppm

Source: Spheight (1999)

Table 3 Elemental Composition of Cassava Starch

Element	Weight %
Carbon	75.16
Iodine	3.02
Silver	2.37
Calcium	2.20
Potassium	2.22
Titanium	1.39
Sulfur	2.04
Sodium	2.40
Chlorine	1.54
Silicon	1.66
Oxygen	2.52
Phosphorus	1.06
Aluminum	1.16
Magnesium	0.63
Nitrogen	0.63

Source: Nwosu (2021)

2.1.5 **The Problem and Plus of Cassava**

The major problem with cassava is spoilage 48 hours after harvest, producing enough flour for food, biofuel, drilling fluids additives, and fiber required without proper storage becomes a problem. Once cassava is dried to a moisture content below 5% or fermented dried processed and frozen this problem is solved. Fermented and dried cassava has a shelf life of more than 5 years when stored in dry containers but packaging and transportation become bulky when frozen than when dried.

2.2 **My Contributions to Knowledge**

To engineer local materials using unit operations and design units for industrial processing on a large scale, I started by looking into the engineering properties of cassava such as its bulk density, specific heat, thermal conductivity, thermal diffusivity, and mass transfer coefficient which were not available for the design of rotary dryer for drying of cassava in my work.

2.2.1 **Effect of Variety on the Drying and Engineering Properties of FGC**

The emergence of improved varieties of cassava in recent times demands that the effect of variety on the engineering properties of ground fermented cassava (FGC) be determined to generate data for optimum performance of the rotary dryer and design of novel drying techniques for cassava. This work provided data on the engineering properties such as moisture content, bulk density, specific heat, thermal conductivity, thermal diffusivity, and mass transfer coefficient of some cultivars, as well as the effect of variety of cassava on the drying and engineering properties of fermented ground cassava using three high yield improved cultivars (TMS 30555, TMS 30572 and NR 8082) and two native cultivars. A bench rotary dryer was used for drying.

The proximate of the cultivars had a very great impact on their engineering properties see Table 4 and 5. The difference in the drying rate was therefore attributed to the difference in their

Table 4 Variation of Starch and Amylose Content of the Cultivars.

Cultivars	Starch %	Amylose %	Amylopectin %	Water absorption capacity (WAC) %
TMS 96/1632	74.02	19.84	80.16	81.72
TMS 97/2205	80.36	21.56	78.44	81.08
TMS 98/0510	80.55	20.39	79.61	79.24
TMS 98/0040	75.03	22.05	77.95	71.20

Source Eke (2014)

Table 5 Proximate Compositions of Cultivars.

S/N	Sample	Mass fraction of protein (Xp)	Mass fraction of fat (Xf)	Mass fraction of ash (Xa)	Mass fraction of carbohydrate (Xc)
1	Native I	0.018	0.019	0.012	0.65
2	Native II (RED)	0.018	0.014	0.008	0.65
3	TMS 30555	0.009	0.027	0.014	0.70
4	TMS 30572	0.026	0.018	0.022	0.75
5	NR 8082	0.035	0.033	0.016	0.74

Source: Ademiluyi et al (2006)

chemical composition. The specific heat capacity as shown in Table 6 and thermal conductivity (Table 7) of each cultivar varied with the proximate composition; water content, and density; indicating that cultivars with similar chemical composition had the same specific heat capacities. More heat energy would be required to dry cultivars with high fat, protein, and carbohydrate content.

The specific heat capacity ranges between 1.085 – 1.284 kJ/kgK and thermal conductivity which ranges between 0.17- 0.198 W/mK for bone-dry fermented ground cassava of these cultivars. At the same moisture content, the specific heat capacity and thermal conductivity were found to be different for cultivars with different proximate compositions and similar for

Table 6 Model Equations for Specific Heat Capacity (kJ/kgK)

S/N	Sample	Equation
1	Native I	4.180Xw + 1.085
2	Native II (RED)	4.180 Xw + 1.068
3	TMS 30555	4.180Xw + 1.155
4	TMS 30572	4.180Xw + 1.256
5	NR 8082	4.180Xw + 1.284

Source: Ademiluyi et al (2006)

The drying rates, thermal diffusivity and mass transfer coefficient of each cultivar vary with proximate composition, porosity, product surface area, and the change in density after drying of each cultivar (Ademiluyi *et al*, 2006).

The thermal diffusivity of each cultivar varied with proximate composition, porosity, density, as well as moisture content. Fermented ground cassava of any of these cultivars should not be dried below their equilibrium moisture content; otherwise, moisture will be reabsorbed again from the atmosphere. Cultivars with low porosity and low hygroscopic properties exhibited a low rate of mass transfer. The mass transfer coefficient differed for each cultivar and was highest for cultivars with low fat, protein, and carbohydrate content and high drying rate, see Table 8.

Table 7 Determination of thermal diffusivity of each cultivar at 10 % moisture content (dry basis)

Cultivars	Density **kg/m^3**	Thermal conductivity W/m °C	Specific heat Capacity CP kJ/kgK	Thermal diffusivity (x 10 $^{-7}$m^2/s)
Native I	378	0.23	1.50	4.05
TMS 30572	382	0.25	1.67	3.91
TMS 30555	370	0.24	1.57	4.13
NR 8082	406	0.26	1.70	3.76

Source: Ademiluyi et al (2006)

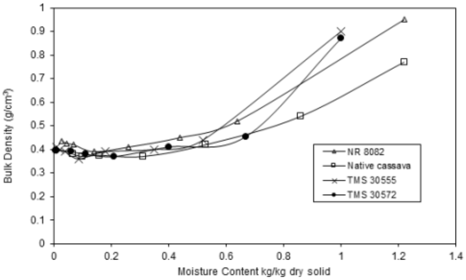


Fig 4 Effect moisture content on the Bulk density during drying of the cultivars

Table 8 Showing effect of Variety on the mean particle size, product surface area, and Mass Transfer Coefficient

Cultivars	Mean Particle Sizemm	Surface area m^2	Density before Drying kg/m^3	Density after Drying kg/m^3	Mass Transfer Coefficient m/s (x 10^{-7})
Native I	745	0.090	770	370	3.609
TMS 30572	717	0.110	870	380	1.668
TMS 30555	686	0.126	900	370	1.189
NR 8082	937	0.179	950	400	0.678

Source: Ademiluyi et al (2006)

Therefore, the same drying conditions cannot be used for drying the different cultivars except they have close engineering properties. The data thus obtained will serve as a useful tool in the development of heat and mass transfer models for drying fermented ground cassava for each of the cultivars studied. These properties and the models developed are necessary for cellular energy demand for the design of a rotary dryer for drying fermented ground cassava. The same was also observed during the drying of different Cassava Chips in Thin Layers

Therefore, the same drying conditions cannot be used for drying the different cultivars except they have close engineering properties. The data thus obtained will serve as a useful tool in the development of heat and mass transfer models for drying fermented ground cassava for each of the cultivars studied. These properties and the models developed are necessary for cellular energy demand for the design of a rotary dryer for drying fermented ground cassava. The same was also observed during the drying of different Cassava Chips in Thin Layers (Ademiluyi *et al.,* 2007a)

The effect of variety on the heat transfer coefficient of four cassava cultivars (TMS 30555, TMS 30572, NR 8082, and one Native type) was also investigated. The cultivars were dried at an air temperature of 142°C, air velocity of 1.02 m/s, and relative humidity of 55%. The heat transfer coefficient obtained varied from 0.0622 – 0.0725 kJ/kg s °C . The heat transfer coefficient varied for some cultivars, while some cultivars had a close heat transfer coefficient. NR 8082 had the lowest heat transfer coefficient while TMS 30555 had the highest heat transfer coefficient. The cultivars with high heat transfer coefficients were found to have lower bulk density, smaller particle diameter, high drying rate, low specific heat capacity, and higher carbohydrate fat and protein content than other cultivars.

At same feed temperature, the product temperature of the feed the air outlet temperature can be monitored as shown Table 9.

Table 9 Temperature Profiles for During Drying the Different Cultivars

Samples	Feed Temp Tf °C	Product Temp. Tp °C	Air Inlet Temp, Tai °C	Air Outlet Temp. Tao °C	ΔT_{LM} °C
NR 8082	28	75	142	102	60.39
TMS 30555	28	70	142	100	62.90
TMS 30572	28	68	142	100	64.53
Native II	27	70	142	100	63.25

Source: Ademiluyi et al (2007)

The difference in the heat transfer coefficient of each cultivar was found to be because of the differences in bulk density, particle diameter, and the chemical composition of the cultivars. Cultivars with low bulk density have a high heat transfer coefficient. Only cultivars with close heat transfer coefficient can be dried using the same drying conditions, and different optimum drying parameters, i.e. temperature, and air velocity should be used for other cultivars like NR 8082 and TMS 30555 with different heat transfer coefficient drying rates as shown in Table 10. Hence, the same heat transfer cannot be used for industrial drying of these different cultivars. Therefore, the same drying condition cannot be used for drying the fermented ground cassava cultivars except they have close engineering properties.

Table 10: Heat and Mass Transfer Coefficient for the Different Cultivars at 10% Moisture Content.

Samples	Heat Transfer Coefficient, hm kJ / kg s.°C	Cs of Dry Solid KJ/kg °C) at 10% moisture	Mass Transfer Coefficient (m/s)	Bulk Density after drying (Kg/m^3)
NR8082	0.0622	1.74	0.678	400
TMS 30555	0.0725	1.62	1.189	370
TMS 30572	0.0667	1.72	1.668	380
Native	0.0671	1.65	3.609	370

Source: Ademiluyi et al (2007)

2.2.2 **Effects of Drying Parameters on the Drying Kinetics of Fermented Ground Cassava Using a Rotary Dryer**

The effects of drying parameters on the drying kinetics of fermented ground cassava (TMS 30572) in a rotary dryer were also carried out using the dryer in Fig 5. The study showed that inlet air temperature and inlet air velocity are the most significant parameters that affect the drying rate of the material and that for proper gelatinization of FGC, the inlet air temperature should lie within the range of 140 – 230°C low inlet air velocity (< 1.55 m/s), low drum drive speed (8 – 12 rpm), and low feed drive speed of about 12 rpm, high mass of feed (>500 g), inlet air temperature in the range 190 — 230°C was recommended for proper gelatinization of FGC

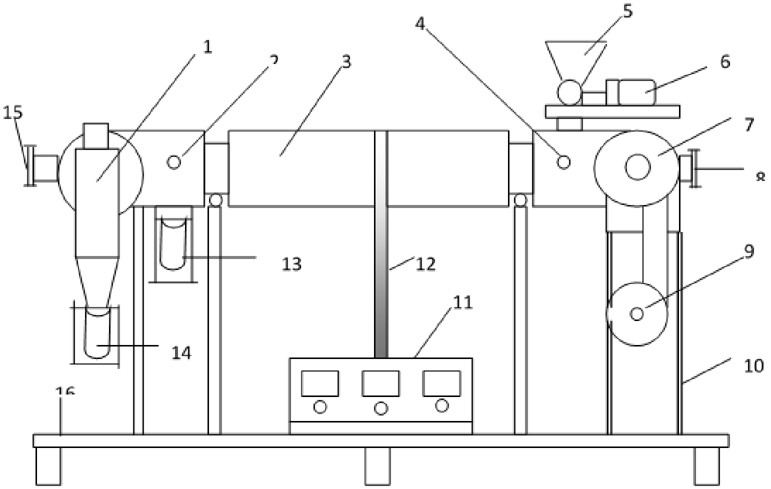


Fig. 5. Schematic diagram of bench scale rotary dryer.

1 cyclone, 2 & 4 probe connections, 3 rotary drum, 5 feed hopper, 6 feed drive, 7 electric heater arrangement, 8 & 15 sight glasses, 9 air blower and orifice plate control, 10 support, 11 control panel, 12 chain drive, 13 &14 dried product receivers, 16 steel table.

A model that predicts the drying rate of the fermented ground cassava as a function of inlet air temperature and inlet air velocity was also presented. Good agreement was obtained between predictions of the model and experimental data.

2.2.3 **Effects of Drying Parameters on heat transfer during drying of FGC in a rotary dryer**

The effects of drying parameters on heat transfer during drying of FGC in a rotary dryer were studied. The FGC was dried in a bench-scale rotary dryer at different inlet air temperatures, inlet air velocity, relative humidity, feed rate, drum drive speed, and feed drive speed. The result showed that inlet air temperature, inlet air velocity, and feed rate, have significant effects on the specific heat-transfer coefficient and heat load in the material, as shown in Table 11a.

Table 11a. Paired samples T-test result of specific heat-transfer coefficient (W/kg ^{o}C) at different drying conditions

Drying parameter	**Paired differences Mean (W/kg ^{0}C)**	**95% confidence interval of the difference lower**	**upper**	**t**	**Stand. dev.**	**Sig. value**	**Corr. coeff.**
Inlet air temperature (^{0}C)	-137.971	-600.352	324.411	-0.950	290.58	0.004	-0.996*
Inlet air velocity (m/s)	-127.517	-280.209	25.174	-2.658	95.958	0.002	0.998*
Feed rate (kg/hr)	-161.458	-261.683	-61.233	-5.127	62.986	0.012	-0.988*
Drum drive speed (rpm)	-236.945	-309.637	-164.253	-10.373	45.683	0.016	0.984*
Inlet air humidity (%)	-101.858	-169.294	-34.424	-4.807	42.379	0.054	-0.946
Feed drive speed (rpm)	-130.428	-184.913	-75.942	-7.618	34.241	0.540	0.460

**Data are significantly different with high correlation coefficient (r^2 ~ 1) and low significant value (< 0.05).*

Source: Ademiluyi et al (2010b)

Table 11a shows that the specific heat-transfer coefficients at the various drum drive speeds, feed rates, inlet air temperature, and inlet air velocity, are significantly different since the correlation coefficient is high ($R^2 \sim 1$) and the significance value is low (< 0.05). The FGC produced does not gelatinize properly at high drum drive speed (> 15 rpm), and low drum drive speed (4-10 rpm) is recommended, within this recommended range of drum drive speed, the specific heat-transfer coefficients are not significantly different; hence, the effect of drum drive speed was neglected in the analysis. Although the specific heat-transfer coefficients at different inlet air humidity are not significantly different due to significance value greater than 0.05, moderate inlet air humidity (50-65%) was recommended for proper gelatinization of FGC.

Thus, the specific heat-transfer coefficient is modeled with respect to inlet air temperature, inlet air velocity, and feed rate. Regression analysis was carried out using Datafit 8.2 engineering software to obtain the relationship between the specific heat-transfer coefficient, inlet air temperature, inlet air velocity, and feed rate, as seen in equation 1a.

$$h = -0.39063\ T_{ai} + 253.5701\ \upsilon_{ai} + 0.1555\ M - 92.026 \qquad (1a)$$

with standard error of estimate (SEE) = 0.356, and correlation coefficient ($_2$r) = 0.9999, and residual sum of square (RSS) = 0.3803, where T_{ai} is the inlet air temperature (^{o}C), υ_{ai} is the inlet air velocity (m/s), M is the feed rate (kg/hr), and h is measured in C.W/kg$_o$

Models that predict the specific heat-transfer coefficient as a function of inlet air temperature and inlet air velocity; and the heat load as a function of inlet air temperature, inlet air velocity, and feed rate, were also presented as seen in the equation. Predictions of the models were compared with experimental data and good agreement is obtained.

2.2.4 **Effects of Drying Parameters on Drying Kinetics of FGC in a Rotary Dryer**

The effects of various drying parameters on the drying kinetics of fermented ground cassava (TMS 30572) in a rotary dryer were investigated. The result showed that inlet air temperature, inlet air velocity, and mass of feed, have significant effects on the moisture ratio during drying of the fermented ground cassava, but the effect of inlet air temperature and inlet air velocity on the moisture ratio is more significant than the effect of the mass of feed as shown in Table 11b. The final moisture content of ground cassava after drying is very important to avoid spoilage and for proper packaging, hence MR is the moisture ratio defined as shown in Equ 1b.

$$MR = \frac{X - X_e}{X_o - X_e} \qquad (1b)$$

Seven widely used thin-layer drying models (see Table 11c) and a newly-proposed thin-layer drying model have also been applied to the drying of FGC, with the **newly-proposed model** (equation 2) performing better than the existing models for all the drying conditions considered in the analysis.

$$MR = a\exp[-(kt)^n] \tag{2}$$

Table 11b. Paired T-test result for constant “”*k* in the newly proposed model at different drying parameters

Drying parameters	Mean value of “*k*”	Standard deviation	Corr. coeff.	Sig. value	t
Air velocity (m/s)	0.8849	0.2729	0.992*	0.006*	6.485
Temperature (^{o}C)	168.398	51.199	0.977*	0.023*	6.576
Mass of feed (g)	7.10E-02	0.3377	-0.911	0.271	0.364
Drum drive speed (rpm)	12.8623	4.2535	0.520	0.480	6.048
Feed drive speed (rpm)	60.1760	38.2642	0.956	0.044	3.145
Air Humidity (%)	63.4076	12.5390	-0.886	0.114	10.114

*Data are significantly different with high correlation coefficient ($R^2 \sim 1$) and low significant value (< 0.05).

Source: Ademiluyi and Puyate (2013)

In order to generate the functional relationships between the constants (a, k, n) of the newly proposed model and their most significant drying parameters as defined in eq. (3), the constants were regressed against those of inlet air temperature and inlet air velocity using multiple regression analysis implemented in statistical software (Datafit, 2000). All possible combinations of the various drying parameters were tested and those with the highest correlation coefficient were chosen as the final models, to obtain Equ 4, 5 and 6.

$$a = 1.8051 - 0.00158T_{ai} - 0.323\upsilon_{ai} \tag{3}$$

with Standard Error = 0.00643 and $R^2 = 0.997$.

$$k = -0.404 + (5.010 - 0.0161T_{ai})^{-1} + 0.206\upsilon_{ai} \quad (4)$$

with Standard Error = 0.0111 and $R^2 = 0.991$.

$$n = 1.374 - 0.0088T_{ai} + 1.118\upsilon_{ai} \quad (5)$$

with Standard Error = 0.121 and $R^2 = 0.937$.

The moisture diffusion coefficient during drying of the fermented ground cassava varies from 1.32×10^{-9} to 3.52×10^{-9} m^2/s with activation energy of 12.935 kJ/kmol for a range of inlet air temperature from 115 °C to 230°C, and varies from 0.5×10^{-9} to 3.257×10^{-9} m^2/s for a range of inlet air velocity from 0.83 m/s to 1.55 m/s. A model which predicts the diffusion coefficient as a function of inlet air temperature and inlet air velocity was presented, and good agreement is obtained between predictions of the model and experimental data as shown in Fig 6

Table 11c Seven widely used thin-layer drying models and a newly-proposed model

Serial No.	Name of model	Model equation
1	Newton	$MR = \exp(-kt)$
2	Page	$MR = \exp(-kt^n)$
3	Modified Page	$MR = \exp[-(kt)^n]$
4	Henderson and Pabis	$MR = a\exp(-kt)$
5	Logarithmic	$MR = a\exp(-kt) + C$
6	Two-term	$MR = a\exp(-k_0t) + b\exp(-k_1t)$
7	Wang and Singh	$MR = 1 + at + bt^2$
8	Newly-proposed model (Ademiluyi)	$MR = a\exp[-(kt)^n]$

Source: Source: Ademiluyi and Puyate (2013)

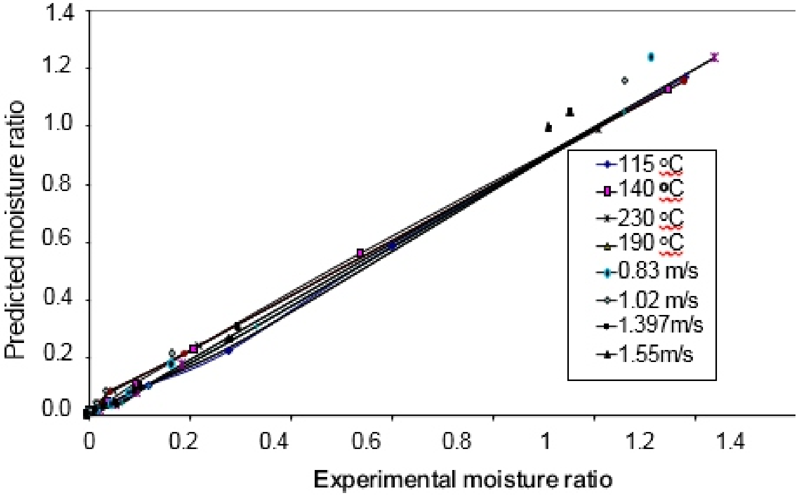


Fig. 6. Experimental and predicted moisture ratio of fermented ground cassava at different drying conditions Source: Source: Ademiluyi and Puyate (2013)

2.2.5 **Theoretical Model for Predicting Moisture Ratio During Drying of Spherical Particles in A Rotary Dryer**

The new theoretical, Abowei-Ademiluyi model was developed for predicting drying kinetics of spherical particles at any known particle diameter, rotary drum diameter, and dryer length. The new model also accounts for the mass of feed.

a) **Theoretical development of thin-layer drying equation**

The Fick's diffusion equation (7) has been accepted for describing the drying characteristics of biological and chemical products in the falling rate period [McCabe *et al*, 1987].

$$\frac{\partial M}{\partial t} = \frac{\partial}{\partial x}\left(D\frac{\partial M}{\partial x}\right)+\frac{\partial}{\partial y}\left(D\frac{\partial M}{\partial y}\right)+\frac{\partial}{\partial z}\left(D\frac{\partial M}{\partial z}\right) \qquad (7)$$

Where D is the diffusion coefficient M is moisture content (dry basis) at any time t and t is drying time. The equation of diffusion for a spherical particle at constant diffusivity and radial (as shown in Fig 7) flux takes the form of equation 8.

$$\frac{\partial M}{\partial t} = D\left(\frac{\partial^2 M}{\partial r^2}+\frac{2}{r}\frac{\partial M}{\partial r}\right) \qquad (8)$$

In order to solve equation 8 the following assumptions were adopted:

- * Moisture movement is only diffusion and unidirectional
- * Diffusion coefficient D is independent of moisture concentration
- * drying process is isothermal i.e adiabatic dryer
- * material to be dried is spherical in shape
- * Shrinkage is neglected.

we reduces equation 8 to 9 $\left(\frac{\partial^2 M}{\partial r^2}+\frac{2}{r}\frac{\partial M}{\partial r}\right) = -\lambda^2$ (9)

Integrating equations 3 using separation of variables gives

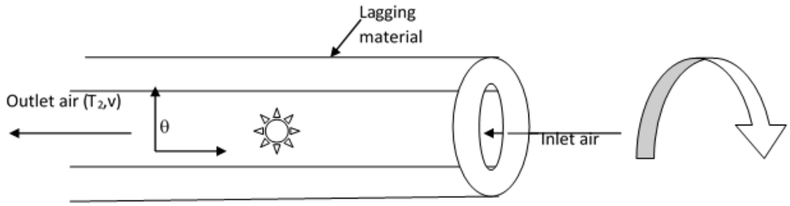


Fig 7 Showing hypothetical profile of moisture diffusion from a spherical particle in a rotary dryer. Source Ademiluyi et al (2013)

Combining equations 5 and 8 gives M (r. t) = R(r) T(t) so that

$$M(r,t) = C_1 e^{-\lambda^2 Dt} \sqrt{\frac{2}{\pi\lambda}} \left[\frac{C_2}{r} Sin\,(\lambda r) + \frac{C_3}{r} Cos\,(\lambda r) \right] \qquad (10)$$

and applying the boundary conditions. The solution to equation 10 in the case of a sphere is expressed as equation 11

$$\frac{\partial M}{\partial r} = 0, \quad r = 0,\ r \geq 0, \quad M = M_e$$

$$MR = \frac{M_i - M_e}{M_o - M_e} = \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} \exp\left[\frac{-n^2 \pi^2 D}{r^2} \right] t \qquad (11)$$

Where,

r `is the radius of grain of FGC,
MR = Moisture ratio
Mo = initial moisture content (% db)
Me = equilibrium moisture content (% db)
Mi = moisture content at time t (% db)
t = drying time (hr)

The work of Abowei (1991) shows that, the mass of hydrocarbon M was accounted for when modeling one dimensional diffusion of oil spill in water and obtain a general solution (equation 12) to predict the diffusion of known quantity of crude oil in water. This equation is analogous to the diffusion equation 11 describing diffusion of moisture out of porous spherical particles

$$\boldsymbol{Cp} = \frac{M_p}{A\left[4\pi D_m \boldsymbol{t}\right]^{1/2}} \boldsymbol{e}^{-x^2/4\boldsymbol{D_m t}} \qquad (12)$$

$$(\text{g/cm}^3)$$

Where Mp in equation 12 is the quantity of oil spilled., Cp is the concentration of oil spilled at any time. A is the area where oil is spill; Dm is the diffusion coefficient and t is the time

Comparing equation (11) with (12), the term

$$\frac{M_p}{A\left[4\pi D_m \boldsymbol{t}\right]^{1/2}}$$

in equation (11) is analogous to the term $\frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}$ in equation (12) and hence equation (11) can be rewritten as

$$\boldsymbol{MR} = \frac{M_p}{\rho A\left[4\pi D_m \boldsymbol{t}\right]^{1/2}} \exp\left[\frac{-n^2\pi^2 D_m}{r^2}\right] t \qquad (13)$$

where MR is the moisture ratio. A is surface area available for moisture transfer which for the

rotary dryer is $\pi(R^2 + RL)$ and M_p is the mass of FGC to be dried. and ρ is the average density of sample to be dried, the density is added to equation 13 to make the equation dimensionless since moisture ratio MR is dimensionless, so that equation 13 becomes

$$MR = \frac{M_p}{\rho(\pi(R^2 + RL))\left[4\pi D_m t\right]^{1/2}} \exp\left[\frac{-n^2\pi^2 D_m}{r^2}\right] t \qquad (14)$$

where, r is the average radius of particle to be dried and R is the radius of rotary dryer drum, L is the length of the rotary dryer and Dm =D is Diffusion coefficient = ***/RT)a(E Exp*** *Do* where E_a is the activation energy. The equation 14 is the new theoretical **Abowei – Ademiluyi model** for predicting the drying of any spherical particles in a rotary dryer. Equation (14) was simulated to obtain the theoretically determined moisture ratio.

Model validation was carried out by drying fermented ground cassava particles in a bench scale rotary dryer at ground cassava particles in a bench scale rotary dryer at inlet air temperatures of 115-230°C, air velocities of 0.89m/s-1.55m/s, feed mass of 50-500g, drum drive speed of 8 rpm, and feed drives speed of 100 rpm. The theoretical moisture ratio calculated from the model compared favorably with experimental moisture ratio.

a) Dimensional Analysis Approach

In order to remove moisture from a moist material in a rotary dryer, the moisture ratio MR can be taken to be a function of the change in temperature ΔT, the quantity of fermented ground

cassava to be dried Mp, the latent heatλ, diameter of particle D to be dried, inlet air velocity v, and drum speed N, so that mathematically the moisture ratio MR is dimensionless as

$$MR = \phi\left[\Delta T, M_p, \lambda, D, V, N\right] \qquad (15)$$

Where ϕ is a correction factor
Applying dimensional analysis we have,

$$\frac{M}{M} = \phi\left[\boldsymbol{T}^{\boldsymbol{a}}, M^{b}, \left(\frac{FL}{M}\right)^{c}, L^{d}, \left(\frac{L}{\theta}\right)^{e}, \left(\frac{1}{\theta}\right)^{f}\right] \tag{16}$$

Applying the Buckingham pi method gives

The dimensionless constant ϕ was evaluated theoretically and experimentally by combining equation 16 and 14 to give the correction factor as:

$$\phi = \frac{\dfrac{M_p}{\rho A\left[4\pi D_m \boldsymbol{t}\right]^{1/2}} \exp\left[\dfrac{-n^2\pi^2 D_m}{r^2}\right] tD}{VN} \tag{17}$$

The diffusion coefficients (DT, DM, DV in m^2/s) in equations 18 - 20 were obtained experimentally at different inlet air temperature (T in ^{o}C), inlet air velocity (V in m/s) and mass of feed (M in kg) from previous work (Ademiluyi 2009) on fermented ground cassava

DT = 9.747x10-8 Exp [- 13892/8.314T] (18) $r^2 = 0.994$

DM = 8.938 x 10-10+5.937 x 10-11*log(M)/M (19) $r^2 = 0.986$

DV = 4.702 x 10-9+ (-8.49 x 10-9) Exp (-V) (20) $r^2 = 0.990$

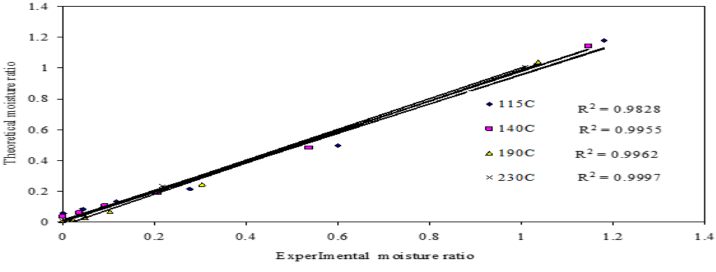


Fig 8 Theoretical (Abowei- Ademiluyi model) and experimentally moisture ratio at different inlet air temperature
(Source Ademiluyi et al, 2013)

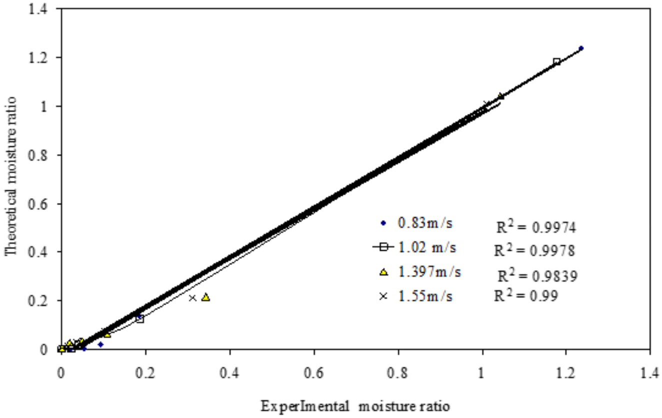


Fig. 9 Theoretical (Abowei- Ademiluyi model) and experimentally moisture ratio at different inlet air velocity (Source Ademiluyi et al, 2013)

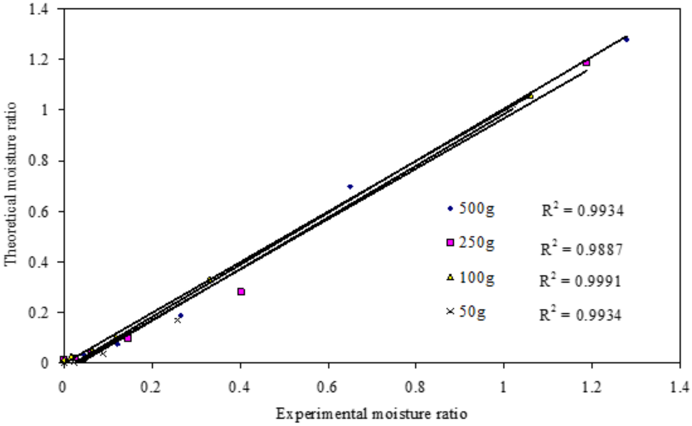


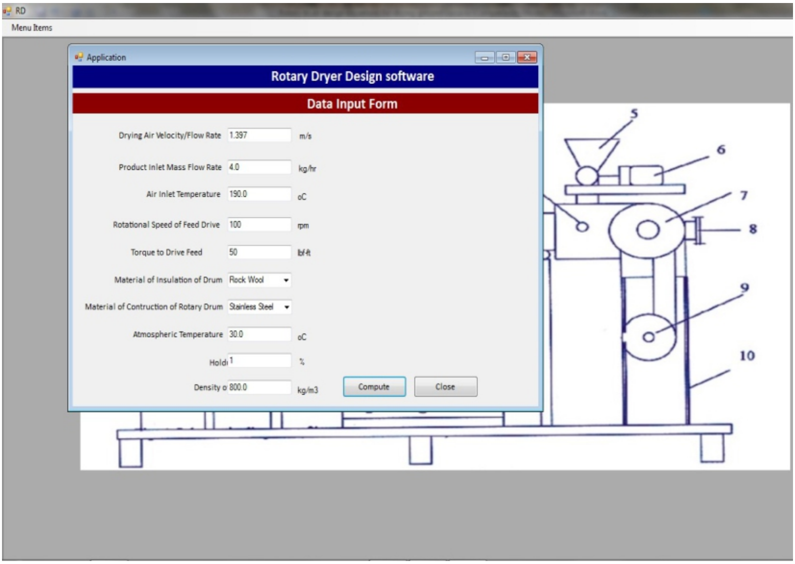
Fig.10 Theoretical (Abowei- Ademiluyi model) and experimentally moisture ratio at different mass of feed . (Source Ademiluyi et al, 2013)

2.2.6 Development of Software for Design and Construction of Rotary Dryer for Drying Ground Cassava

Development of Software for Design and Construction of Rotary Dryer for Drying Ground Cassava was carried out in this study. A program was written using Microsoft Visual Basic. NET 2013. All the basics equations which are needed for the design of part of the dryer were inculcated in the design. A graphic user-friendly interface and 2D/3D graphics for the determination of heat load required for drying, diameter of dryer, length of dryer, design of number of flights, radial height of flight, the thickness of rotary shell, the thickness of insulation, air blower power, the power of the motor for feed drive, the power of motor to drive drum of dryer and the total heat resistance through the dryer were developed.

A click on the compute box lunches the data output form and all the parameters needed for the design of the rotary dryer is displayed as shown in Fig. 11.

Fig 12 Output data window for ground cassava rotary dryer design software The speed of rotation of the rotary dryer drum is also displayed on Fig 12. In practical terms this can only be achieved by installing a speed controller alongside the motor for the rotary dryer. The speed controller must be installed to step down the speed at which the feed is driven through the feed

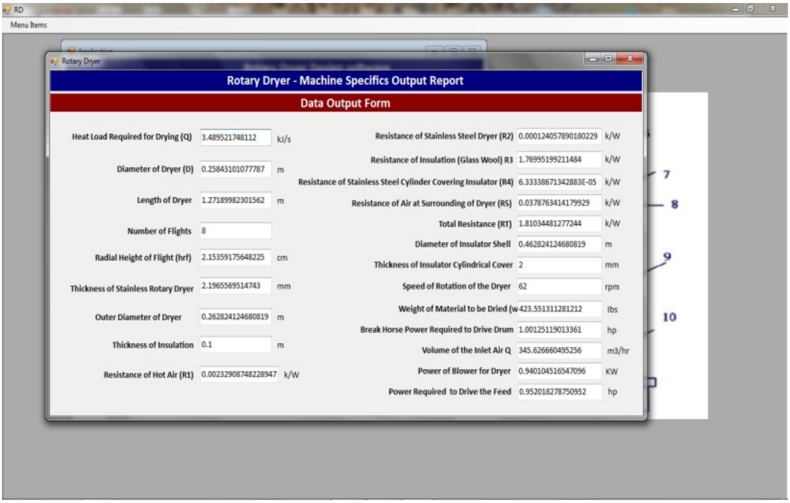


Drying Air Velocity/Flow Rate 1.397 m/s
Product Inlet Mass Flow Rate 4.0 kg/hr
Air Inlet Temperature 190.0 oC
Rotational Speed of Feed Drive 100 rpm
Torque to Drive Feed 50 lbf-ft
Material of Insulation of Drum Rock Wool
Material of Contruction of Rotary Drum Stainless Steel
Atmospheric Temperature 30.0 oC
Holdı 1 %
Density o 800.0 kg/m3

Fig 11 Input data window for ground cassava rotary dryer design software (Source Ademiluyi 2016)

hopper since manufacturers speed of most motors are high than 1000rpm.The power of the motor of the air blower and the power for the feed drive motor were also displayed in Fig 12.

The data generated from the Experimental work and soft software developed was also used to construct a bench scale rotary dryer Fig 13 and 14. This software developed a useful tool for engineers, operators, and designers of rotary dryer for drying ground cassava.



Rotary Dryer - Machine Specifics Output Report

Data Output Form

Heat Load Required for Drying (Q) 3.489521748112 kJ/s

Diameter of Dryer (D) 0.25843101077787 m

Length of Dryer 1.27189982301562 m

Number of Flights 8

Radial Height of Flight (hrf) 2.15359175648225 cm

Thickness of Stainless Rotary Dryer 2.1965569514743 mm

Outer Diameter of Dryer 0.262824124680819 m

Thickness of Insulation 0.1 m

Resistance of Hot Air (R1) 0.00232908748228947 k/W

Resistance of Stainless Steel Dryer (R2) 0.000124057890180229 k/W

Resistance of Insulation (Glass Wool) R3 1.76995199211484 k/W

Resistance of Stainless Steel Cylinder Covering Insulator (R4) 6.33338671342883E-05 k/W

Resistance of Air at Surrounding of Dryer (R5) 0.0378763414179929 k/W

Total Resistance (RT) 1.81034481277244 k/W

Diameter of Insulator Shell 0.462824124680819 m

Thickness of Insulator Cylindrical Cover 2 mm

Speed of Rotation of the Dryer 62 rpm

Weight of Material to be Dried (w 423.551311281212 lbs

Break Horse Power Required to Drive Drum 1.00125119013361 hp

Volume of the Inlet Air Q 345.626660495256 m3/hr

Power of Blower for Dryer 0.940104516547096 KW

Power Required to Drive the Feed 0.952018278750952 hp

Fig 12 Output data window for ground cassava rotary dryer design software (Source Ademiluyi 2016)

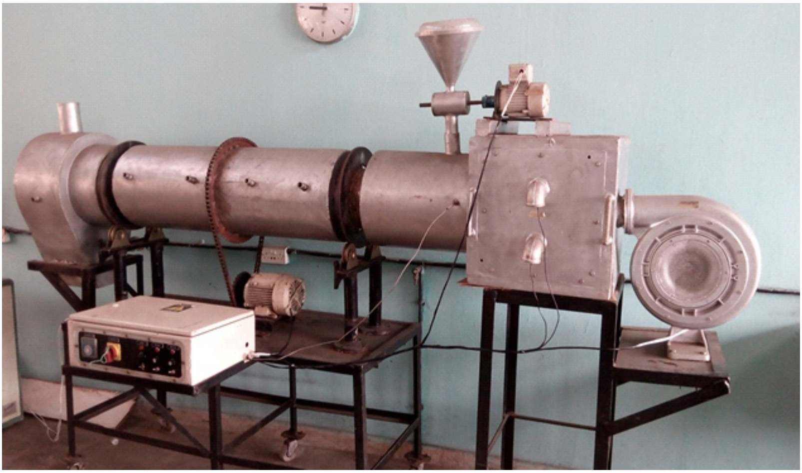


Fig 13 Rotary dryer Constructed (Source Ademiluyi et al, 2016)

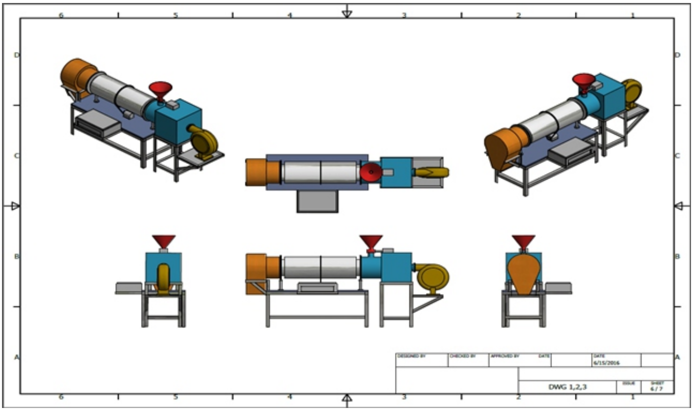


Fig. 14 Showing Pictorial Diagrams of Rotary Dryer Constructed at Different Elevations.
(Source Ademiluyi et al, 2016)

Vice Chancellor Sir, Raw Materials Research and Development Council Nigeria (RMRDC) Abuja sponsored the design of the development of this software through a national grant from a competition organized by the National Mathematics Center, Abuja and I won first prize. Plus, a grant I obtained from the Tertiary Education Trust Fund, Nigeria (TETFund) through our university provided funds also for the construction of the Rotary dryer.

2.3 Ethanol from Cassava Research

2.3.1 Uses of Ethanol

* Ethanol is used as antifreeze, biofuel, solvent for perfumes, for paints and tinctures, preservatives in cosmetics

and medicine, hand sanitizer, cleaning agent, good heat source with minimum carbon monoxide and nitrogen oxides, etc.

* Ethanol is used in the preparation of other chemicals. Ethanol is industrially used in the manufacture of chemicals like **acetaldehyde, acetic acid, diethyl ether, ethyl esters ethylene,** among other chemicals that are used to produce other products.

* It may also be used to dissolve the chemicals as it dissolves both polar and non-polar substances. Also, the production of ethylene from bio-ethanol has the potential to open a new pathway for the synthesis of petrochemicals from a non-petroleum environmentally friendly feedstock (Dilek, 2010)

2.3.2 Ethanol Biofuel Produced from Different Whole Cassava Flours

The yield and properties of ethanol biofuel produced from five different whole cassava flours were investigated. Ethanol was produced from five different whole cassava flours. The effect of quantity of yeast on ethanol yield, effect of whole cassava flour to acid and mineralized media ratio on the yield of ethanol produced see Table 12a, and the physical properties of ethanol produced from different cassava were investigated.

Physical properties such as distillation range, density, viscosity, and flash point of ethanol produced differ slightly for different cultivars, while the yield of ethanol and electrical conductivity of ethanol from the different cassava cultivars varies significantly. The variation in mineral composition of the different whole cassava flours could also lead to variation in the electrical conductivity of ethanol produced from the different cassava cultivars.

Table 12a: Yield, volume, and density of ethanol produced from different cassava cultivars

Name of cassava	Density of first distillate (g/ml)	Density of second distillate (g/ml)	% Ethanol (Weight in water)	Volume of ethanol produced of (ml)/g cassava	Appearance
TMS 92B/00068	0.9432	0.8206	88.7	0.60	Colorless
TMS 92B/00061	0.9506	0.8292	85.4	0.50	Colorless
TMS 91/02324	0.9409	0.8825	86.9	0.55	Colorless
TMS 98/0505	0.9572	0.8284	85.7	0.42	Colorless
TMS 98/0581	0.9463	0.8371	82.5	0.51	Colorless

(Source Ademiluyi & Mepba 2013)

Table 12b Average starch, dry matter, protein content, cyanide and yield per hectare of Fresh cassava cultivars used.

Cassava cultivars	Starch Content %	% Protein	Dry Matter %	% Cyanide level	Yield of fresh cassava root tonnes/ hectares
TMS 92B/0068	67.15	1.72	28.235	4.91	26.07
TMS 92B/0061	65.90	2.71	35.63	3.95	29.35
TMS 91/02324	67.75	4.55	27.615	6.81	21.09
TMS 98/0505	49.82	3.42	34.18	2.01	29.03
TMS 98/0581	47.04	3.22	35.22	2.60	25.67

Source: IITA Onne report (2010)

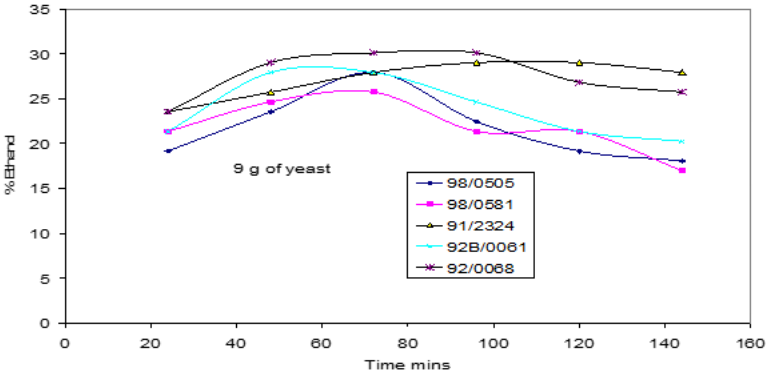


Fig 15 Ethanol yield for different cassava cultivars (Source Ademiluyi & Mepba 2013)

The differences in ethanol yield are attributed to differences in starch content, protein content, and dry matter of cassava cultivars. A high yield of ethanol from whole cassava flour is best produced from cultivars with high starch content, low protein content, and low fiber as shown in Table 12b.

Table 13 shows the viscosity, electrical conductivity, and flash point of ethanol from different whole cassava fours. The viscosity and flash point varied slightly while the electrical conductivity of ethanol from the different cassava cultivars varied significantly. The electrical conductivity of fuel ethanol is an important parameter used when measuring fuel quality. A conductivity of not more than 500 s/m is recommended. The values obtained for cassava ethanol (82.7-88.5%) for all the cultivars are still within the required range of 500 s/m and higher conductivity can be obtained when further distilled to give 96% ethanol and flash point of 14°C

Table 13 Electrical conductivity, Viscosity, and flash point of ethanol from different whole cassava flours

Type of Cassava used	Electrical conductivity (µs/m)	Viscosity (CST)	Flash point (°C)
TMS 92B/00068	329	1.99	15
TMS 91/02324	330	2.1	18
TMS 92B/0061	230	2.0	24
TMS 98/0505	300	2.02	19
TMS 98/0581	150	2.2	23

(Source Ademiluyi & Mepba 2013)

2.3.3 **Ethanol Production Worldwide**

Worldwide fuel ethanol production climbed to over 28 billion gallons in 2022. This was an increase of 850 million gallons compared to the previous year and the highest figure in the seven-year period shown. Ethanol is one of the most common types of biofuels consumed and derived primarily from crops such as corn. (Stastica, 2023). Nigeria is the largest in terms of cassava production but no record of ethanol export from Nigeria as shown in Fig 16.

2.3.4 **China bioethanol plant**

Under the Development Plan for Renewable Energy in the Eleventh Five-Year Plan in the People's Republic of China, the target was to increase the production of ethanol fuel from nongrain feedstock to 2 million metric tons (2,000,000 long tons; 2,200,000 short tons), and that of biodiesel to 200 thousand metric tons (200,000 long tons; 220,000 short tons) by 2010. This is equivalent to the replacement of 10 million metric tons (9,800,000 long tons; 11,000,000 short tons) of petroleum. The **100,000-ton ethanol production** facility is located in Haikou, in the southern islands of China. The Haikou plant will also be producing **20,000 tons of (compressed) carbon dioxide per year as a by-product**. The Beijing government is reported to have recently banned the use of grain-based feedstocks (such as corn) for bioethanol production amid concerns that these feedstocks might have a negative impact on food supplies, Cleantech (2008).

2.3.5 Brazil Bioethanol Plant

Brazil is one of the biggest producers of bioethanol worldwide, **using sugarcane** as the main raw material in the first crop generation. However, geographical limitations and food versus fuel debate have prompted to search for alternative sources of biomass since the demand for bioethanol continuously increases. Lignocellulose (second-crop generation) can represent a valuable chance to grow the ethanolic biorefinery sector which stimulates the efforts of different Brazilian research centers and resulted in two industrial plants with several difficulty to validate this technology at large scale. Thus government, institutions, and researchers are trying to apply the concept of biorefinery to reduce production costs and to adapt existents plants to operate simultaneously first–second-ethanol generation. Third-crop generation (micro- and macroalgae) is studied but without perspectives for large-scale exploitation.

2.3.6 United States Bioethanol Plant

The United States produces and consumes renewable energy sourced from agriculture and forestlands on a commercial scale that impacts energy markets. Significant biofuels include ethanol (**made mostly from corn**), and biodiesel and renewable diesel (which are made from vegetable oils as well as animal fats, waste oils, and greases). In 2022, U.S. ethanol production totaled about 15.4 billion gallons and combined biodiesel/renewable diesel production totaled about 3.1 billion gallons USDA (2022).

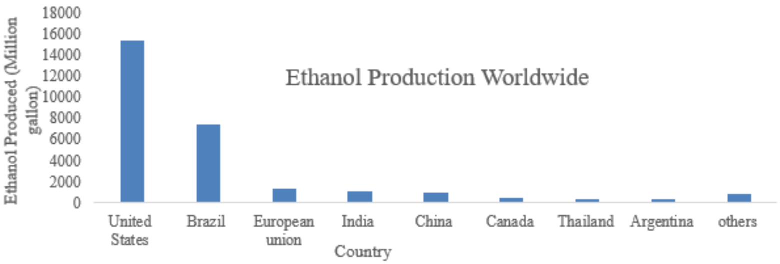


Fig 16 Ethanol Production Worldwide (Stastica, 2023)

2.4 Drilling Fluids Additives Using Different Cassava Flours

2.4.1 Investigation of Local Polymers (Cassava Starches) as a Substitute for Imported Sample in Viscosity and Fluid Loss Control of Water Based Drilling Mud

Comparative study of local polymer (cassava) with an imported type in controlling viscosity and fluid loss in water-based mud was investigated in this study. Five different cassava starches were tested as viscosifiers and fluid loss control additives in water-based mud and compared with an imported sample. Table 14 shows functional properties of local starches used in formulation of water-based mud.

Table 14 Functional properties of local starches.

S. No.	Type of cassava	Mud types	Amylose (%)	Starch (%)	Swelling power (%)	WAC (%)	Dry matter (%)
1	TMS 30572	Mud A	27.69	74.21	9.04	122.45	95.13
2	TME 419*	Mud B	18.97	70.87	-	-	-
3	TMS 95/0289	Mud C	23.93	85.24	11.58	86.98	91.41
4	TMS 91/02324	Mud D	21.45	78.54	11.43	96.22	94.33
5	TMS 96/1642*	Mud E	22.77	67.36	-	-	-

Source: Onitilo et al, (2007), Eke et al., (2010) Ademiluyi et al, (2011)*

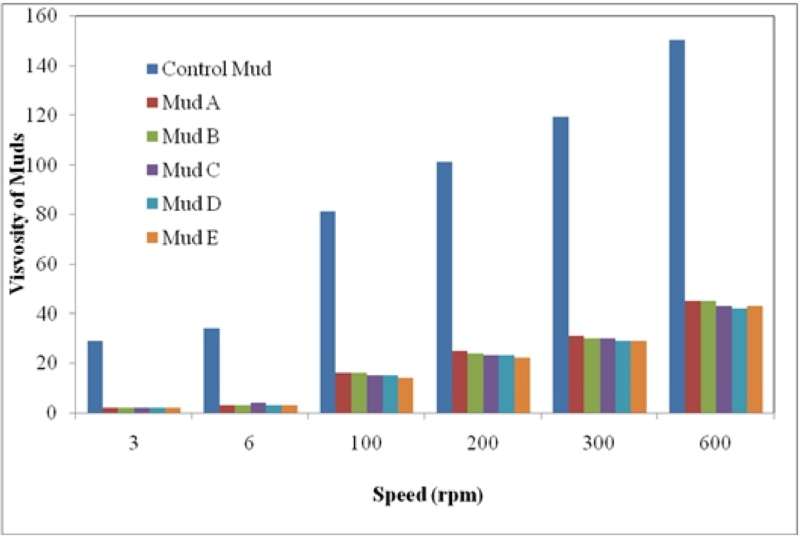


Figure 17 Viscosity of drilling fluids in (Cp) at different speed before aging at 80°F. Source: Ademiluyi et al, (2011)

Experimental results indicated that at same concentration, the imported sample had higher rheological properties compared with the local samples, but the rheological properties of the mud formulated were still within the API values of more than 35cp at high speed.

However, some of the newly developed local starch products (with high amylose content and high-water absorption capacity) have similar or better filtration control properties than the imported sample (Fig 17-18). Although the viscosity of the drilling fluid produced from the local starches were lower than

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that of the imported type, with proper quality control efforts of the local samples, they could be used as a substitute for imported grade for exploration and exploitation of oil and gas in Nigeria. Local starch could be used as a substitute for imported sample to control viscosity and fluid loss in water-based drilling muds. Samples with highest amylase content and high-water absorption capacity produced drilling fluid with higher viscosity and lower fluid loss. This no doubt will provide economic benefit to Nigerian farmers '

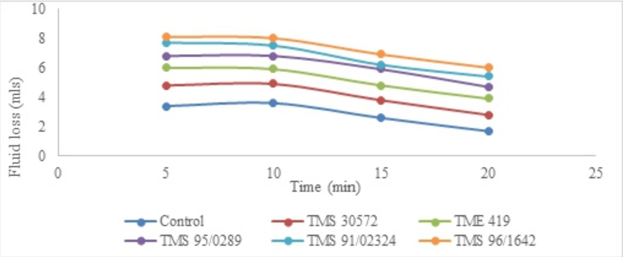

Fig 18 Fluid loss with time before aging at 80°F (Source: Ademiluyi et al, (2011)

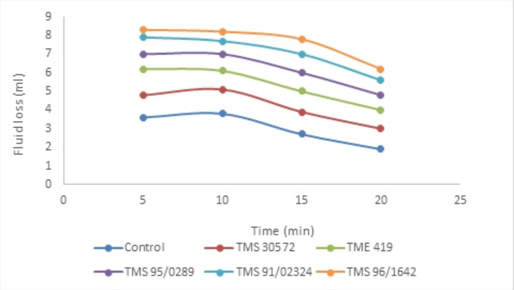

Fig 19 Fluid loss with time after aging at 80°F (Source: Ademiluyi et al, (2011)

2.5 Performance Evaluation of More Local Cassava Starches with Imported Starch for Drilling Fluid

Bentonite muds were formulated with the more new local cassava starches and rheological and filtration tests were performed. The bentonite mud formulated with TMS 98/0581 was next in performance to the best performed bentonite mud sample formulated from the imported starch. TMS 96/1632 starch formulated bentonite mud performance significantly lower than the others. The mineralogy, crystalline index, particle size and crystalline index of starch favour the performance of bentonite mud. Imported starch could be substituted with local cassava TMS 98/0581 starch as drilling fluid additive. The structural properties of starches contributed to their behaviours in drilling fluid performance.

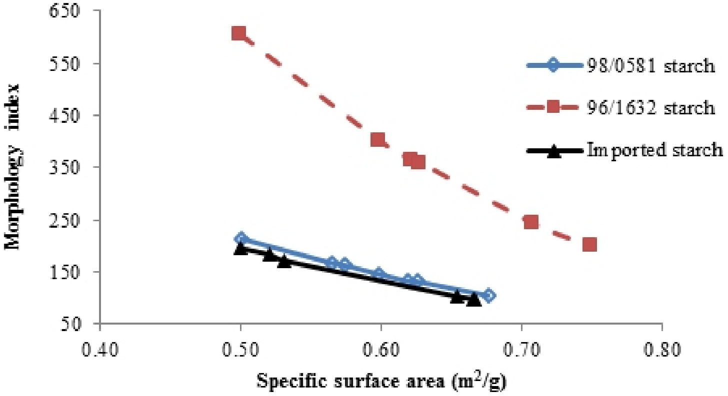

Figure 20: Morphology index versus specific surface area

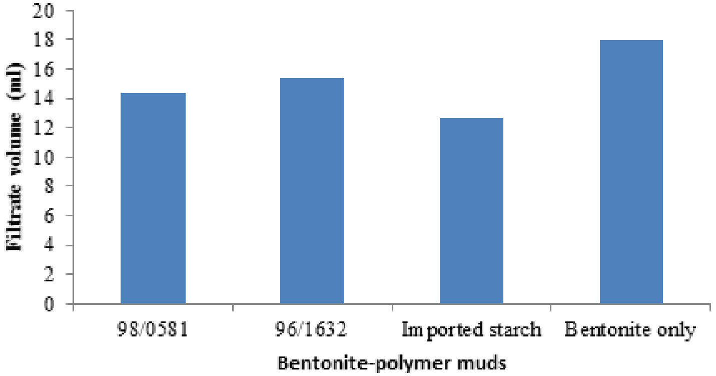

Figure 21: API fluid losses of bentonite muds at 0.5% polymer concentrations

2.6 Performance Evaluation of Bentonite Muds Formulated using Cassava Starch Treated with Preservatives

A determination and analyses of the rheological characterization and filtration properties of the **sixty one (61) mud samples** from the three cassava starch cultivars of TMS 92/0057, TMS 98/0581 and TMS 96/1632 treated with the four preservatives at varying concentrations was made. The analyses were made with respect to the AP1 standard specifications (AP1 2004). It was only the following five muds that met the threshold of the specifications; A2, A7, A8, B7 and C7.

Muds A7, C7, A8 and B7 were all formulated with TMS 98/0581 starch cultivar, containing 0.05% benzoate, 0.05%

sorbate, 1% benzoate and 0.05% propionate, respectively. Mud A2 was a formulation of TMS 92/0057 with 0.05% benzoate. In advancing this work, therefore, it is evident that the benzoate could be considered as an appropriate preservative at low concentrations in formulation with TMS 98/0581 and TMS 92/0057 starch cultivars. It is instructive to note that the findings of previous researchers on this subject matter posited similar observations as to the promising potentials of these cassava starch cultivars as effective colloids for water-based drilling fluids formulations (Ademiluyi *et al*., 2011, Harry *et al.,* 2016). Most importantly, the characterization of the control starch mud sample E1 compares very favourably with these recommended samples but particularly mud samples A2 and A7.

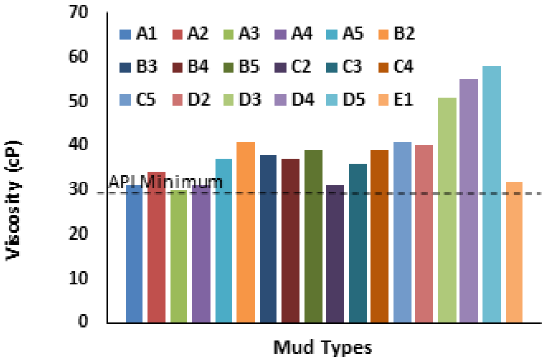

Fig. 22: Mud Viscosity for TMS92/0057 starch muds treated with different preservatives (Source: Nwosu , ***Ademiluyi ,*** *& Joel , 2021)*

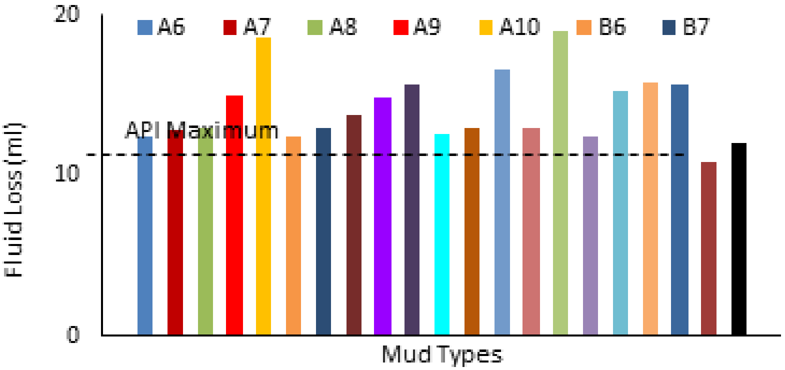

Fig. 23: Fluid Loss for TMS 96/0581 Starch-Bentonite Formulated Muds. (Source: Nwosu, ***Ademiluyi*** *, & Joel 2021)*

2.7 Modelling and Rheological Characterization of Bentonite Muds Formulated using Cassava-Starches Treated with Preservatives

In this study, two local cassava cultivar starches; TMS 92/0057 and TMS 98/0581 were stabilized by the addition of salts of benzoate, sorbate and propionate as preservatives and mixed with bentonite. The rheology tests were carried out at 80^0F, 120^0F, 150^0F and 190^0F. The experimental data was applied to four rheological models. The Herschel Bulkley model presented the best correlation to the experimental data, to be followed by the Casson model. Bingham Plastic model overestimates the shear stress while Power Law model does underestimation. The yield stresses showed positive and progressive temperature dependence. The flow behaviour indexes did not indicate any clear or patterned temperature relationship. The mud rheology presented pseudo-plastic and shear thinning profiles and good thermal stability which is desirable features for productive drilling campaigns. Therefore, applying the Herschel-Bulkley model to predict shear stress-shear rate relationships for drilling muds of this cassava-starch formulation is an opportunity to be explored in furtherance of the local content drive in the Nigerian oil and gas industry.

The rheogram of the comparative performance of the muds A2, A7, A8, B7, and C7 at various temperatures were shown in Figures 6 to 9. At 80°F muds, A2 and B7 posted the least (10.65 Pa) and the highest (40.47 Pa) shear stress values, respectively. Mud B7 had consistent high shear stress all through its profile with a clear linear section of the shear stress – shear rate plot. Muds A2 and A8 showed more irregular profile. At 120°F muds, A7 and C7 paired in having the least shear stress value while mud B7 had the highest value of 15.98 Pa and 38.34 Pa, respectively. All the muds posted a fairly uniform profile for both the linear and non-linear segments of their rheogram.

At 150°F mud, A2 indicated the highest consistent shear stress profile while the least low shear rate stress value of 22.37 Pa was indicated by mud C7. A stable profile was posted by all the muds at this temperature. The 190°F rheogram of the muds had a similar feature as in the 150° profile with muds C7 and A2 having the least and highest shear stress values of 24.50 Pa and 46.86 Pa, respectively. Therefore, apart from at 80°F where mud B7 indicated the highest shear stress values, mud A2 led in the remaining temperatures while mud C7 largely had the least values in all the temperatures. The general trend, therefore, is that the shear stress increases with temperature as corroborated by Harry *et al.*, 2017.

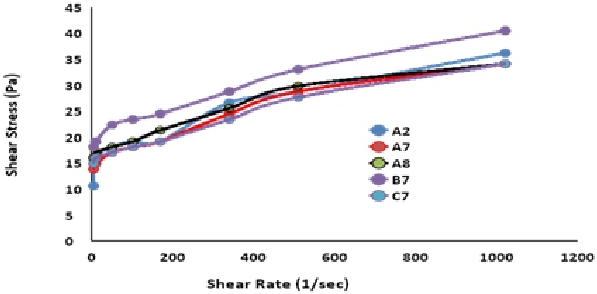

Fig. 24: Comparative rheogram of all the muds @ 80^0F. Source: (Nwosu, Ademiluyi....Akpa (2021)

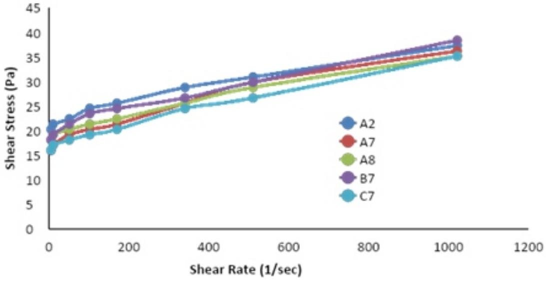

Fig. 25: Rheology models predictions for mud A2 at 80^0F (Source: (Nwosu, Ademiluyi....Akpa (2021)

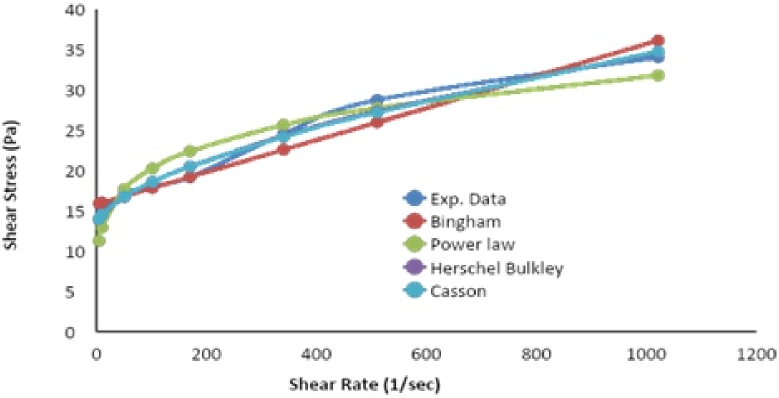

Fig. 26: Rheology models predictions for mud A7 at 80^{0}F
Source: (Nwosu, Ademiluyi....Akpa (2021)

Other PhD Researches on use of local cassava starch as drilling fluid additives carried out under my supervision are:

- Kinetic Modeling of Drilling Mud Treated with Local (Cassava) and Imported Polymers.
- Rheological Model Parameters for Bentonite Drilling Mud Treated with Local Cassava Starch
- Applications of Starches from Selected Local Cassava as Drilling Mud
- Potency of starch in hydrate inhibition in a field within Gulf of Guinea Using Aspen Hysys.

3. PYROLYSIS

Vice Chancellor Sir, another area of unit operation, I researched was pyrolysis. Pyrolysis is the thermal degradation of plastic waste at different temperatures (300–900°C), in the absence of oxygen, to produced liquid oil (Rehan *et al.,* 2017).

3.1 Pyrolysis of waste water sachets for the production of fuel oil

Potentials of waste water sachets for the production of fuel oil were evaluated. In this work, waste polyethylene (pure water sachets) was pyrolysed at different temperatures: 130 - 190°C, 200 -300° C, and 300 - 450°C using a batch reactor. Below 200°C, 78% of the waste was converted to wax, 18% to fuel oil and 3% to non-condensable gases. The wax content decreases as temperature increases. The highest quantity of fuel oil was produced between 300°C - 450°C.

Fig 27 Waste Water Sachets Source: Ademiluyi and Akpan (2007)

Fresh samples of the waste were pyrolysed at higher temperature range from 50^0C – 250^0C and cooled in a condenser. The non-condensable gas produced were collected and analyzed with Shimadzu gas chromatography. The analysis shows that C1 – C6, and other alkenes and isoparaffins (18 ethylene monomers) were produced. The gaseous products being 75.82% propylene at low temperatures and 48.6% (normal and Iso) butane at higher temperatures

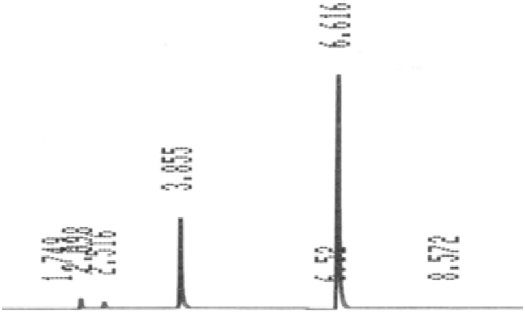

Fig 28 Retention time versus concentration for gaseous products (25 – 140^0C) Source: Ademiluyi and Akpan (2007)

Table 15: Gas Chromatography result of Analyzed gas (25 – 140^0C).

Retention Time (mins)	Components	Names	Concentration (mol/dm^3)	% Composition
2	C_2H_6	Ethane	0.0040	2.5
4	C_3H_8	Propane	0.0344	21.7
7	C_3H_6	Propylene	0.1205	75.8

Source: Ademiluyi and Akpan (2007)

Table 16: Analysis of non-condensable gaseous products (50 – 250^{0}C) with gas chromatography

PKNO	Time	Composition	Compound
1	2	6.8	CH_4
2	2.	1.2	C_2H_6
3	3	2.2	C_2H_4
4	4	2.4	C_3H_8
5	7	3.4	C_3H_6
6	8	23.2	Iso-C_4H_{10}
7	9	25.4	n-C_4H_{10}
8	14	13.5	t-2-C4
9	15	9.1	1-C_4H_8
10	16	8.6	c-2-C4
11	18	7.5	Iso- C_5H_{12}
12	21	0.5	Methyl acetylene
13	22	0.5	n-C_5H_{12}
14	23	0.5	1,3-Butadiene
15	24	0.2	C6PLUS
16	25	0.9	C6PLUS
17	25	0.6	C6PLUS
18	25	0.2	C6PLUS

Source: Ademiluyi and Akpan (2007)

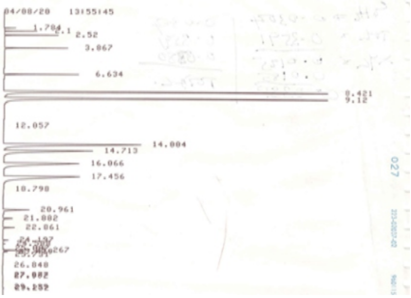

Fig 29 Retention time versus concentration for gaseous products (50 – 250^{o}C) Source: Ademiluyi and Akpan (2007)

The chromatographic analysis shows that the fuel oil produced (up to 450°C) contains paraffins, isoparaffins, olefins, naphthalenes, aromatics and polyaromatics ranging from C3 – C38. It could be refined further to produce domestic kerosene and gasoline. The physical and structural properties of the fuel oil produced compared favorably with that of Aviation fuel JP-4 (a wide-cut US Air force fuel). Presently African countries are importing aviation fuels. The fuel oil produced from the pyrolysis of waste water sachets can therefore be used in place of JP–4, providing the aviation industry with a cheaper fuel oil from a cheaper source (waste water sachets) than crude oil. The pyrolysis of these waste water sachets will also enhance proper waste management of the menace created by the usage of these waste polyethylene sachets in our society.

Table 17. Typical properties of fuel oil produced up to 450°C and JP 4(Aviation fuel)

Parameters	Properties Unit Fuel Oil produced from water sachets	JP- 4 (aviation oil)*
Hydrogen content %	14.75	13.5
Distillation range	360	40-270
API	57	45-57
Density at 15°C g/cm^3	0.751	0.751-0.802
Physical state	Liquid	Liquid
Flammability	Flammable at room temperature	Flammable

Source: Ademiluyi and Akpan (2007)

Table 18 shows the summary of flame test carried out at different temperatures. At low temperatures the flame is non-luminous and burns continuously from 50°C -140°C, with a pale blue flame. As the temperature increases the flame becomes more luminous (yellowish). At 400°C the gaseous product reduced and by 550°C no more gaseous product were produced. This shows that proper condensation of the gaseous products is required in order to produce clean gaseous fuels from the pyrolysis of the waste sachets.

Table 18: Summary of Flame Test

Temperature (°C)	Types of Flame
50 – 140	Burns with a blue flame
150 – 200	Yellow flame appears on the blue flame
200 – 300	Blue flame reduces with more yellow flame
400	Bright yellow flame
500 – 550	Yellow flame reduces graduall y

Source: Ademiluyi and Akpan (2007)

Pyrolysis of low-density polyethylene waste will not only reduce the solid waste by over 80% volume but will also result in production of 75.82% propylene gas at low temperature which can be used to produced polypropylene, another useful packaging material. At higher temperature, 48.57% (iso and normal) butane was produced. These non-condensable gases produced during the formation of fuel oil from waste polyethylene can serve as feedstock and fuel gas.

3.2 Polyethylene Wax Produced from Pyrolysis of Waste Polyethylene Sachets

Waxes are used in the manufacture of candles for religious and decorative purposes, in polishes, matches, waxed paper, and cosmetics. Waxes are also generally used in the manufacture of rust preventives, crayons, rubber antioxidants, electrical insulators, paper coatings, printing inks, textile finishes, and leather dressings.

Polyethylene waste was converted to polyethylene wax with a yield of over 90% optimum pyrolysis temperature of $130^{o}C$-$140^{o}C$ and optimum pyrolysis time of 20-30 minutes. The polyethylene wax obtained has a melting point of $76^{o}C$-$142^{o}C$ and penetration degree of the polyethylene wax obtained is 1-40.6mm. Pyrolysis at high temperature at $150^{o}C$ and above results in low yield especially when pyrolysis time was increased. Waste sachets pyrolysed at 130-$150^{o}C$ for 30-40 minutes produce high-quality polyethylene wax (paraffin and microcrystalline wax) from waste polyethylene water sachets with yield of above 75%, good melting point and penetration degree. Hence waste water sachets can be used to produce microcrystalline polyethylene wax of high quality with great economic potentials. (Source: Ademiluyi, Oboho & Akpan , 2013)

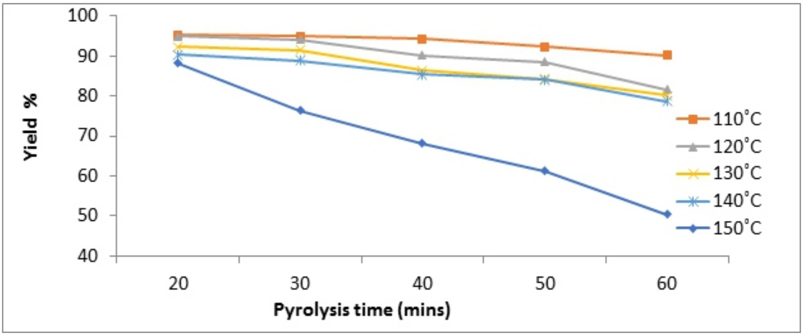

Fig 30a Yield of Polyethylene wax obtained with Pyrolysis Time and Temperature

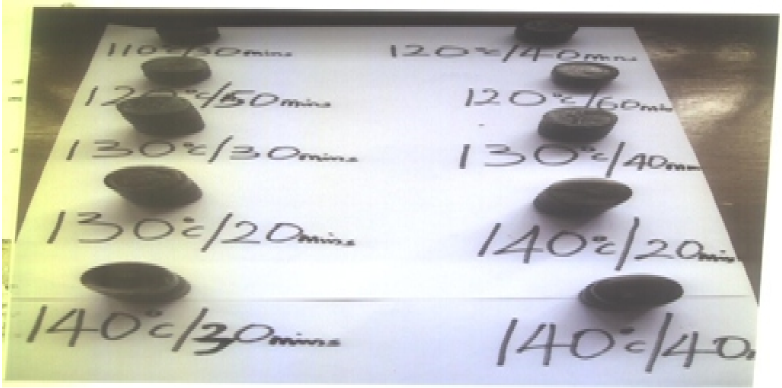

Fig. 30b Polyethylene Wax Produced from Pure Water Sachets Showing Pyrolysis Temperature and Time (Source: Ademiluyi, Oboho & Akpan , 2013)

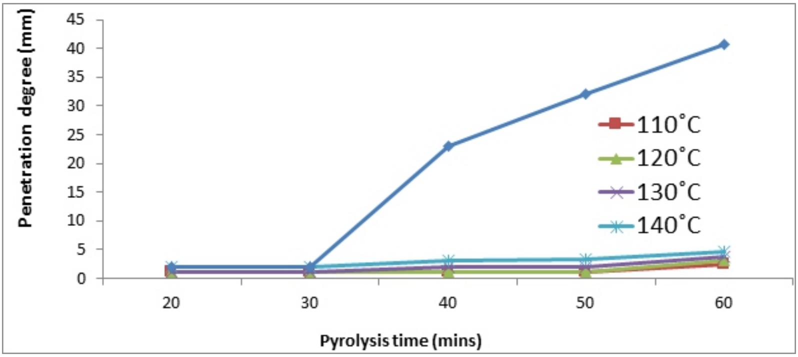

Fig 31 Penetration Degree (0.1mm at 25°C) at Different Temperature and Pyrolysis Time (Source: Ademiluyi, Oboho & Akpan , 2013)

3.3 Shoe Polish Formulated from Wax Produced from Waste Water Sachets

Wastewater sachets were pyrolyzed at various temperatures to obtain wax. Quality polyethylene wax with good penetration degree was produced between 130ŏC and 150ŏC and used to produce the polish. Three different formulations of polishes were prepared from the waste polyethylene wax and the properties of the three samples were compared with the two standard polishes (Kiwi and Lude). The melting point, pour point (°C), density and viscosity of the polish formulated using 12% waste polyethylene wax, compared favorably with standard commercial polish. The conversion of the waste sachets to wax in formulating polish will not only be commercially viable but will reduce environmental pollution.

Table 19 Viscosity (Secs) of Formulated and Control Polish

Temperature (°C)	A	B	C	D	E
40	2.39	Too hard	0.57	Too viscous	8.24
50	2.03	Too hard	0.33	Too viscous	3.67
60	0.35	Too hard	0.19	0.69	3.14

Source: (Source: Ademiluyi, & Ameh, 2013)

Table 20. Showing Melting Point, Pour Point (°C) and Density of Polishes

Parameters	Formulated and Control polish				
	A	B	C	D	E
Melting point (°C)	28	>60	>60	32	39
Pour point (°C)	-8	-18	-12	-7	-5
Density (g/ml)	0.63	Too hard	0.68	0.62	0.62

Source: (Source: Ademiluyi, & Ameh, 2013)

3.4 **Physiochemical Properties of Fuel Oil from Pyrolysis of Palm Kernel Shell**

PKS was collected from different geographical locations, identified and authenticated before it was washed, sun dried and crushed to a standard grade of 425 åm. The PKS was later pyrolysed in the reactor from 400 to 450°C. The fuel oil product was passed through a condenser submerged in ice bath for cooling to 10°C.

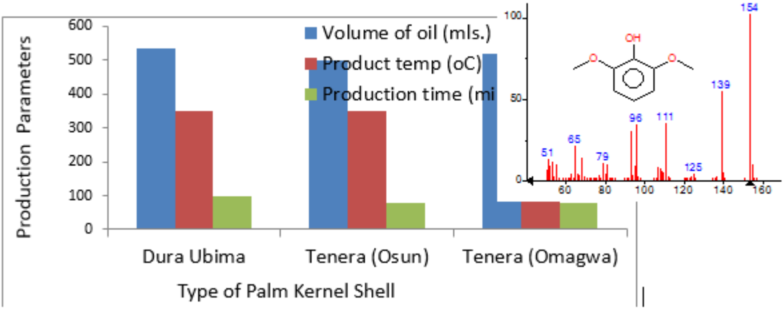

Fig. 32 Production Parameters of Different Palm Kernel Shell Source: Ajayi, Ademiluyi & Ukpaka (2020)

The structural elucidation of oil produced from pyrolysis of PKS using Gas Chromatography-Mass Spectrometer in this technique, the measurement of the molecular weight of the compounds were determined from which the molecular ions were identified and measured to ascertain the exact number of hydrogen, carbons, oxygen and other atoms that were present in the molecule in order to give the molecular formula. The energy required to pyrolyse the PKS was 841500KJ while the product temperature and the atmospheric temperature were 723K and 378K respectively. It was concluded that the fuel oil produced from the designed PKS pyrolyser met the specifications of fuel oil JET A2 kerosene.

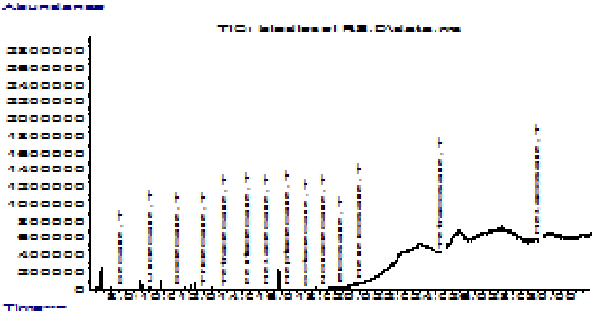

Fig 33: Gas Chromatography/Mass Spectroscopy for the Hydrocarbon Content and the Fuel Oil from Palm Kernel Shells

Fuel oil of 36.65% was recovered from Dura specie of PKS obtained from Ubima (Rivers State) after pyrolysis, with a higher heating value of 42.2 MJ/Kg, and a flash point of 37.9°C, API gravity at 15°C was found to be 37.29 with density of 828kg/m^3. The physical and chemical properties of the biofuel, produced from different PKS species is presented in Table 20. The heat required for pyrolysis of 1000kg/day of palm kernel shell was also obtained.

Table 21 Physical Properties of Fuel Oil Produced from Palm Kernel Shells

Physical Properties	Unit	ASTM	Present Work	Jet Fuel A2
Specific gravity at 15°C		D1298	0.8285	0.8308
API at 15°C		D287	39.29	37.9
Density at 15°C	g/m^3	D1298	828	-
Saybolt viscosity at 15°C	mm^2/s	D445	6.42	8
Sulfur content	%	D4294	0.66	0.33

Flash point	°C	D56	38	37.9
Pour point	°C	D97	-11	0 – 40
Distillation range	°C	D86	28-250	204
Water content	%	-	2.4	-
Ash Value	%	D482	0.132±0.04	<0.01%
Heat of combustion	MJ/Kg	D3338	42.2	42.8
Thermal conductivity at 15°C	W/mK		0.29	-
Total carbon	%	D189	64.2	-
Specific heat capacity at 15°C	KJ/Kg K		1.89	

Source: Ajayi, Ademiluyi & Ukpaka (2020)

3.5 **Design of Pyrolyzer for the Production of Fuel Oil Using Palm Kernel Shells.**

The Design of a pyrolyser for pyrolysis of 1000kg/day of Palm Kernel Shells was carried in this study. The quantity of PKS pyrolysed affected the pyrolysis temperature and time. The volume of pyrolyser required to pyrolyse 1000kg/day of palm kernel shells was found to be $107.143m^3$. The thickness of pyrolyser was 5mm and material of construction of stainless steel and the lagging thickness of 0.1m. The height of the pyrolyser was found to be 8.15403m with the diameter of 4.0771m. The decomposition reaction constant (k) oil of the fuel oil obtained was determined to be $1.153x10^{-4}s^{-1}$ and the overall constant K was calculated to be $3.17x104s^{-1}$. Energy requires to pyrolyse the PKS was 841500kJ. The results obtained from this work can be used to scale up design of pyrolyser for production of fuel oil from palm kernel shells.

Table 22: Final Design Specifications of Pyrolyzer for 1000kg/Day Capacity Size of Palm Kernel Shells

Specifications of the Reactor	Dimension	Unit
Height	8.15402	m
Diameter	4.07701	m
Volume	107.1429	m3
Heat Required for pyrolysis	14,025	kJ/hr
Internal Temperature (Tai)	723	K
Outside Temperature Tout	378	K
Stainless steel shell thickness for internal	5	mm
Mild Steel Thickness for external	5	mm
Reaction Constant (K) for Oil	1.53×10^{-4}	s^{-1}
Overall Constant (K)	3.17×10^{-4}	s^{-1}
Lagging Insulating Thickness thickness	0.10	m
Thickness of cover Plate	5	mm
Lagging Material		glass wool
internal Resistance R_1 for Hot Air	2.51×10^{-4}	K/W
Resistance R2 for internal Stainless Steel Material	2.798×10^{-6}	K/W
Resistance R3 for the Insulating Material thickness	2.3194×10^{-3}	K/W
Resistance R4 for Mild Steel Thickness	1.904×10^{-4}	K/W
Resistance R5 for the Air Surrounding the Reactor	6.0265×10^{-4}	K/W
Total resistanc e RT across the reactor thickness	3.578×10^{-3}	K/W

Source: Ajayi, Ademiluyi & Abowei (2020)

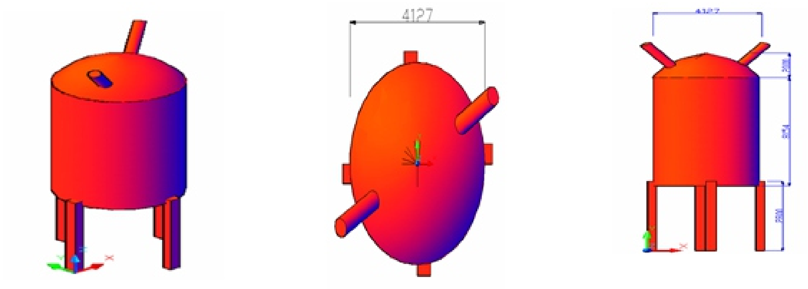

Fig 34: 3D and First Angle Autographic View of the Batch pyrolyser for PKS. Source: Ajayi, Ademiluyi & Ukpaka (2020)

4. ADSORPTION

Adsorption, is a unit operation process in chemical engineering which refers to the collecting of molecules by the external surface or internal surface (walls of capillaries or crevices) of solids or by the surface of liquid Solids that are used to adsorb gases or dissolved substances are called adsorbents; the adsorbed molecules are usually referred to collectively as the adsorbate. Nigeria is blessed with these raw materials we can covert to adsorbent such as bamboo, Palm kernel shells, coconut shell, palm bunch etc. the first I worked on was our Nigerian bamboo.

4.1 Use of Adsorbents

Some of the uses of this adsorbents are:

* Water treatment (Removal of heavy metals, hydrocarbon in water, dissolve solids etc)

- Gas masks with adequate adsorbents are used to protect against harmful gases including chlorine (Cl_2), methane (CH_4), sulphur dioxide (SO_2), and others. The adsorbents adsorb toxic gases preferentially, purifying the air we breathe. Activated charcoal's thin layer absorbs dangerous gases in the most common type of gas mask.
- Removal of gases: Nitrogen from air, Hydrogen from syngas, Ethene from methane and hydrogen, Vinyl chloride monomer (VCM) from air.
- Removal of odours from gases, Recovery of solvent vapours
- Removal of SO_X and NO_X, Purification of helium, Clean-up of nuclear off-gases, Water purification, etc.
- Applications of Adsorption are commonly employed to remove unwanted colourants from raw sugar solutions including vegetable oils, juices, petroleum, and other materials. Animal charcoal, Fuller's earth, activated charcoal, and other adsorbents are employed
- The uses of activated carbon in medical fields are vast. It was used in the cure of many illnesses like gas problems, skin issues, teeth problems, and deodorant. Soonmin (2022)

Vice Chancellor Sir, my research work on local materials for use as adsorbent had to start with characterizing our local materials after activation to see if it's as good as the imported types. The first adsorbent produced was from waste Nigerian Bamboo from a construction site on campus.

Fig 35 Waste Bamboo stem from Construction site on Campus

4.2 Effect of Process Conditions on the Characterization of Activated Carbon from Waste Nigerian Bamboo

The effect of process conditions on the characterization of activated carbon from waste Nigerian bamboo was investigated. The bamboo was pyrolysed and activated using different concentration of hydrochloric acid. The research work, showed that granular activated carbon from waste Nigerian based bamboo acidified with 0.1M hydrochloric acid and activated at 800°C has the best properties when compared with other reference activated carbon. Hence it can be used for both liquid and gaseous phase purification since it has high bulk density, high pore volume, high porosity, high yield, high adsorptive content, and low ash content, low average particle size. Therefore, the best process condition for the production of activated carbon from waste Nigerian based bamboo was 0.1M of hydrochloric acid and 800°C of activation temperature. Activated carbon produced from waste Nigerian based bamboo is from a cheap source, which also, adds value to our economy and solves several adsorption problems in our environment and industry. (Source: Ademiluyi, Gumus; Adeniji & Jasem, , 2009)

4.3 Effect of Activating Agents on the Adsorption of BTX Vapour and Aqueous BTX was Investigated.

The effectiveness of Nigerian Bamboo activated with different activating agents on the adsorption of BTX was investigated. Three bamboos from different locations in Rivers State were used. A series of activated carbons was prepared from Nigerian based bamboo, carbonized at 400°C – 500°C and impregnated with different concentrations (ranging from 0.025M – 0.5M) of phosphoric acid, trioxonitrate (v) acid, and tetraoxosulphate (vi) acid at 800°C in a muffle furnace for 2 hours. The resultant products were further adsorbed into BTX in aqueous and vapour phases.

Table 23: Physical Geometry of Bamboo Types Used

Sample	A (mm)	B (mm)	C (mm)
Average nodal distance	403	315.67	351.67
Inner diameter	6.20	5.33	2.93
Outer diameter	7.75	8.3	4.5
Thickness	0.65	1.43	0.9

Source: Ademiluyi & Braide. (2012)

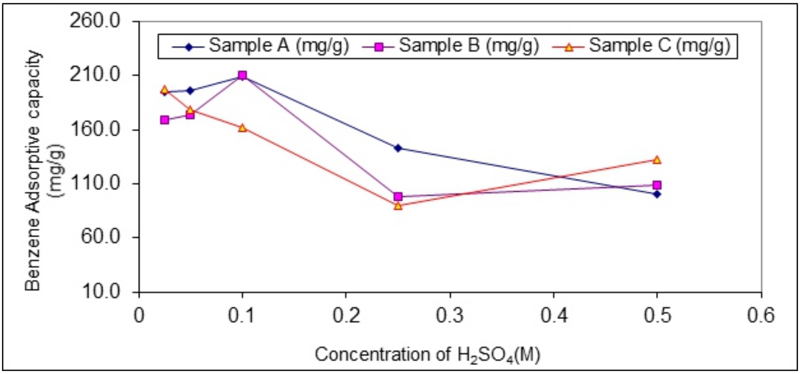

Fig 36 Benzene vapour adsorption using different bamboo activated with tetraoxosulphate (vi) acid (H_2SO_4)
Source: Ademiluyi **&** *Braide. (2012)*

Benzene adsorption was found to increase at low concentration (0.1- 0.143M) for bamboo activated with hydrochloric acid, trioxonitrate (v) acid, and tetraoxosulphate (vi) acid while increasing phosphoric acid concentration during activation was found to increase benzene vapour adsorption. The best activating agent for adsorption of BTX vapour was 0.143M trioxonitrate (v) acid.

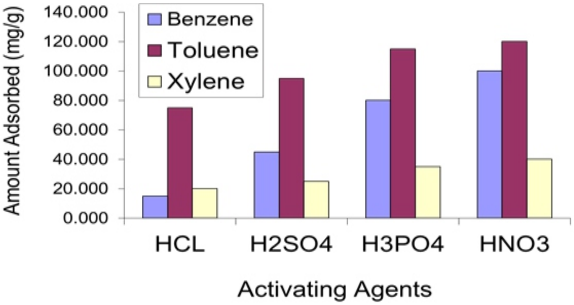

Fig 37 BTX vapour adsorption using bamboo activated with different agent. Source: Ademiluyi & Braide. (2012)

Hence the activating agent for activating bamboo for adsorption of BTX in aqueous solution was hydrochloric (0.1M) and trioxonitrate (v) acid (0.1-0.143M). adsorption of BTX which was found to be more of chemisorptions than on the physical geometry of the bamboo but by the chemical composition of the bamboo and type of activating agent used.

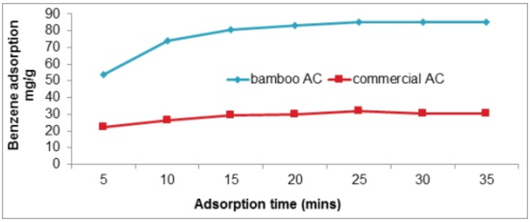

Fig 38 Kinetics of Benzene Vapour Adsorption (mg/g) Using Activated Carbon from Bamboo and Commercial Carbon. Ademiluyi & Braide. (2012)

The activated carbon from bamboo with the best concentration was also found to adsorb BTX favourably and better than a commercial activated carbon with same particle size.

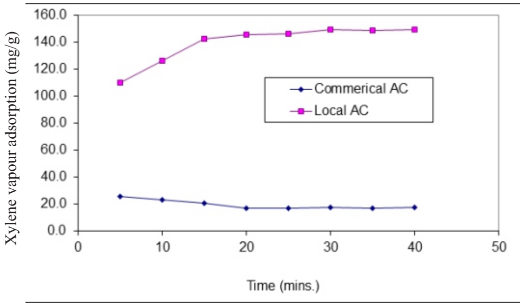

Fig 39 Kinetics of Xylene Vapour Adsorption (mg/g) Using Activated Carbon from Bamboo and Commercial Carbon. Ademiluyi & Braide. (2012)

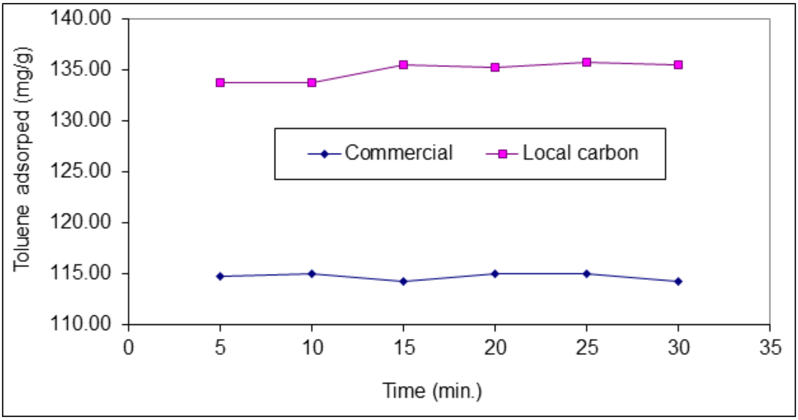

Fig 40 Kinetics of Toluene Vapour Adsorption (mg/g) Using Activated Carbon from Bamboo and Commercial Carbon. (Ademiluyi & Braide, 2012)

Best activating agent for activating bamboo for adsorption of BTX in aqueous solution was hydrochloric (0.1M) and trioxonitrate (v) acid (0.1 – 0.143M). Adsorption of BTX which was found to be more of chemisorption than ordinary physical adsorption. Bamboo type was not affected by the physical geometry of the bamboo but by the chemical composition of the bamboo and type of activating agent used. The activated carbon from bamboo with the best concentration was also found to adsorb BTX favorably and better than a commercial activated carbon with same particle size.

Vice Chancellor Sir, other single metal ion adsorption researches carried by me using activated carbon from waste

Nigerian based bamboo are listed below.

* Kinetics of batch adsorption of iron II ions from aqueous solution using activated carbon from waste Nigerian based bamboo **….Ademiluyi** & Ujile (2013)

* Effect of process parameters on the single adsorption of Zinc and Nickel ions using activated carbon from waste Nigerian bamboo **Ademiluyi** & Nwanam (2016)

* Batch Adsorption Kinetics of Zinc Ions Using Activated Carbon from Waste Nigerian *Bamboo* Ademiluyi & Abidde (2016)

4.4 The adsorption and treatment of organic contaminants in refinery waste using activated carbon from waste Nigerian bamboo

The adsorption and treatment of organic contaminants using activated carbon from waste Nigerian bamboo was investigated. Waste Nigerian bamboo was carbonized at 400oC-500oC and activated with acidat 800°C to produce granular activated carbon (GAC). Adsorption of organics from the refinery waste on the activated carbon produced was examined at 28°C. The organic concentration expressed as chemical oxygen demand (COD) was reduced from an initial value of 378 mg/l to 142 mg/l for the first hour, 143 mg/l for the second hour, 152 mg/l for the third and fourth hours, and 156 mg/l for the final hour., which also compare favorably with the refinery effluent specification of 150 mg/l Results from the study shows that waste Nigerian bamboo can be converted into high capacity adsorbent and used for the remediation of polluted industrial waste waters.

Table 24: Refinery Effluent before and after treatment with activated carbon from waste Nigerian based bamboo

Parameters	Feed waste water before Treatment	Effluent water after Treatment
pH	8.50	6 – 8.5
BOD (mg/l)	260.00	10 – 20
COD (mg/l)	500.00	150
Oil content	200.00	5
Suspended solids (ppm)	100.00	5
Phenol (ppm)	32.00	0.05
Cyanide (mg/l)	28.00	1.0
Ammonium ions (ppm)	73.10	15
Chromium (mg/l)	28.00	0.03
Temp °C	15 – 35	28

Source: Ademiluyi, Amadi & Nimisingha (2009)

4.5 Multiple batch adsorption of different heavy metal ions in aqueous solution using activated carbon from Nigerian Bamboo has been investigated.

The sorption characteristics of multiple and simultaneous adsorption of six heavy metal ions often found in refinery waste waters using activated carbon from Nigerian bamboo was studied. Refinery waste water used for this research was obtained after the treatment plant of the refinery and still has a conductivity of 82 S. Hence the metal ions in the waste water from the refinery was analyzed before and after treatment with bamboo activated carbon. In Fig 37, the concentration of metal ions mg/L was plotted against metal ions in refinery waste water before and after adsorption along with the World Health Organization's (WHO) standard on the maximum allowable limit of these metal ions in waste water.

The concentration of these heavy metal ions was high before adsorption from the treated refinery waste water as shown in Figure 37. Lead, Nickel and Cadmium in refinery waste water before adsorption was higher than the quantity required by WHO while the concentrations of Chromium, Copper and Zinc in refinery waste water before adsorption were below the concentration required by World Health Organization. The concentrations of metal ions after adsorption with bamboo carbon reduced drastically. In fact Copper and Chromium were adsorbed completely, which shows the effectiveness of activated carbon from Nigerian Bamboo. The result was compared with WHO standards as shown in Fig. 37 and this result also showed that Bamboo activated carbon adsorb metal ions in same aqueous solution competitively or selectively. After adsorption with Bamboo activated carbon, the amount of metal ions available was too small to study the adsorption until equilibrium is reached because the refinery wastewater was already treated. Hence metallic salts containing these metal ions were used for the study.

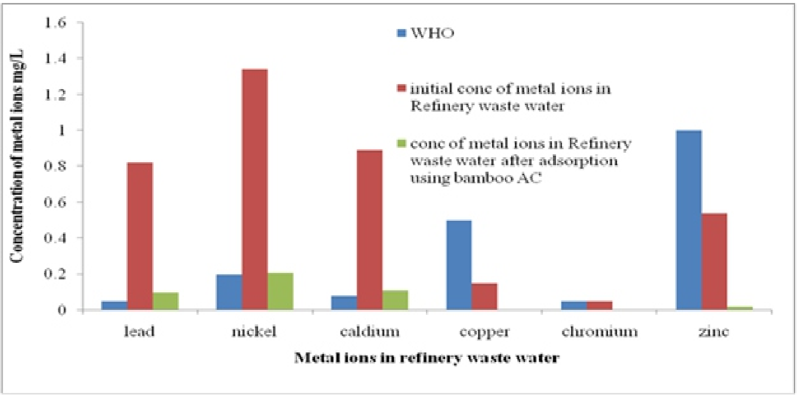

Fig 41 Concentration of metal ions mg/L in refinery waste water before and after adsorption and WHO standards. (Source: Ademiluyi and Nze , 2016)

The results obtained from equilibrium study on batch adsorption of these heavy metal ions when present in waste water. An increase in contact time resulted in increase in the quantity of metal ions are adsorbed in the following affinity order of adsorption Pb>Cd>Cu>Zn>Ni>Cr. Lead ions was the most adsorbed and Nickel ions the least absorbed in the same aqueous solution. The order of adsorption is related to the maximum adsorption of lead, cadmium, copper on bamboo was found to be in the order of ionic radius of the heavy metals ions of Nickel, Copper, Zinc, Lead, Cadmium, and Chromium can help resolve many resolve many adsorption challenges in the industry and in water purification processes. This research work on multiple adsorption of different heavy metal ions in an aqueous solution using activated carbon from Nigerian Bamboo has also contributed to the search for less expensive and easily available material for adsorption and separation process.

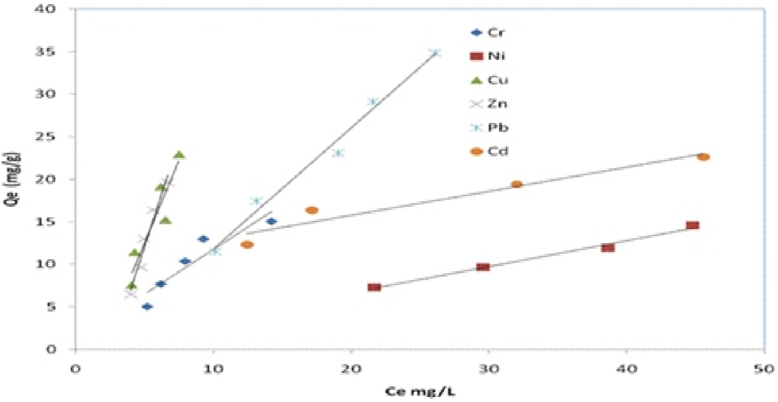

Fig 42 Quantity of Adsorbate Adsorbed at Equilibrium against Equilibrium Concentration (Source: Ademiluyi and Nze , 2016)

The sorption characteristics of multiple and simultaneous adsorptions of six heavy metal ions often found in refinery waste waters using activated carbon from Nigerian bamboo was studied. The experimental data were more consistent for Freundlich, Temkin best fit the sorption process than Langmuir. Adsorption isotherms showed that there is competition among various metals for adsorption sites on Nigerian bamboo. The nature of the sorption process occurring during the adsorption process was found using the DRK isotherm model to be physical and chemical, with sorption energy ranging from (7-10kJ/mol). The high multiple adsorption intensity (n>1 for most of the metal ions adsorbed) of activated carbon from Nigerian Bamboo and its affinity for metal ions of Lead, Cadmium, Nickel, Copper, Zinc, and Chromium can help resolve many adsorption challenges in the industry and in water purification processes.

The kinetics modeling for the design of an adsorber for multiple adsorptions of heavy metal ions was carried out using activated carbon from waste Nigerian bamboo. In order to determine the mechanism of sorption of these heavy metals' ions, the kinetic data were modeled using the pseudo-first order, pseudo-second order kinetic equations, and intra-particle diffusion models. The pseudo-second-order equation was the best applicable model to

Table 24 Freundlich, Temkin and Langmuir isotherm constants related to adsorption of different metal ions from aqueous solution using activated carbon from Nigerian Bamboo.

S/N	**Freundlich Isotherm**				**Temkin Isotherm**			**Langmuir Isotherm**		
	Metal ions adsorbed	**K_f**	**n**	**R^2**	**a**	**b**	**R^2**	**Q_{max}**	**b**	**R^2**
1.	Ni	2.355	1.0846	0.992	-34.79	12.9	0.986	11.299	0.014	0.939
2.	Cu	1.592	0.560	0.925	-24.39	23.7	0.974	23.310	0.067	0.830
3.	Zn	6.761	0.364	0.967	-29.61	26.1	0.967	86.355	0.012	0.918
4.	Pb	1.132	0.886	0.982	-45.05	24.3	0.998	126.58	0.008	0.977
5.	Cd	4.395	2.315	0.946	-12.46	9.22	0.968	56.818	0.018	0.837
6.	Cr	2.432	0.640	0.975	-10.06	9.58	0.981	39.062	0.024	0.891

Source: (Ademiluyi and Nze, 2016)

describe the sorption process. Hence the pseudo second-order kinetic reaction is the rate-controlling step with some intra-particle diffusion taking place.

Figures 38 -39 show the pseudo first, second order kinetic model plot as well as the intraparticle diffusion model plot for multiple adsorptions of heavy metal ions same solution using activated carbon from Nigerian bamboo at 28°C. The trend of the plots are similar to that reported earlier for single metal adsorption. The amount of metal ions adsorbed increases generally with time. Selective adsorption is still exhibited by bamboo-activated carbon for the different metal ions in solution with more affinity for lead and cadmium. The linearity of the three plot shows that the adsorption mechanism is not only taken place at surface but combined with diffusion and chemisorption.

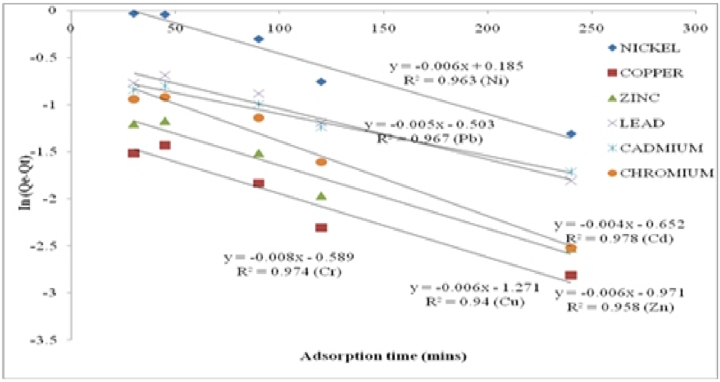

Fig 43 The Pseudo First Order Kinetic Model for Multiple Adsorption of Heavy Metal Ions in Solution using Activated Carbon from Nigerian Bamboo (Ademiluyi and Nze , 2016)

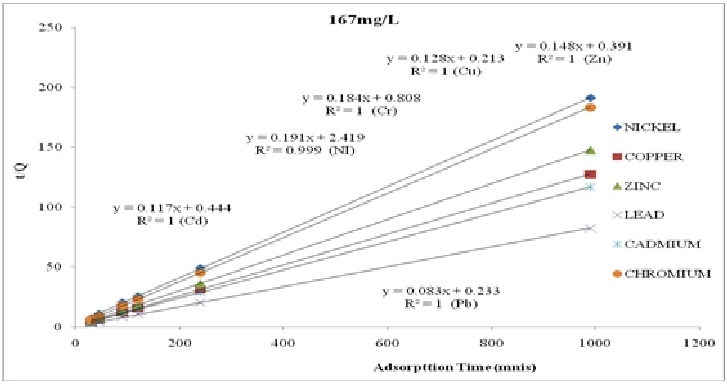

Fig 44 The Pseudo Second Order Kinetic Model for Multiple Adsorption of Heavy Metal Ions in Solution using Activated Carbon from Nigerian Bamboo (Ademiluyi and Nze , 2016)

4.4.1 Determination of number of adsorption stages required with time.

An empirical model was also developed which can then be used for predicting and designing adsorber for the multiple removal of 99% heavy metal ions at any given initial heavy metal ions concentration and the adsorption time required for any multi-stage adsorption system using Nigerian Bamboo activated carbon. (Ademiluyi and Nze, 2016)

4.6 The effect of activating agents on the characterization of the activated carbon produced from Nigerian-grown bamboo, coconut shell, and palm kernel shell

The effect of activating agents on the characterization of the activated carbon produced from bamboo, coconut shell, and palm kernel shell was investigated. Activated carbons were prepared from bamboo, coconut shell, and palm kernel shell carbonized between 350°C - 450°C and activated at 800°C using different activating agents (HNO_3, HCl, H_2SO_4, H_3PO_4, $ZnCl_2$ and NaOH). The resultant products were further characterized by determining; yield, bulk density, ash content, benzene adsorptive capacity, iodine number, percentage burnt off, pore volume, porosity and methylene blue number. X-ray fluorescence (XRF) and scanning electron microscope (SEM) analysis was also carried out on the samples. Statistical analysis was carried out on the data obtained from characterization with IBM SPSS version 20 to separate the mean using Tukey Honest significance difference at 95% probability. The results show that bamboo activated with $HN0_3$ at 800^0C gives the activated carbon with the highest iodine number of 1194.573 of iodine/kg of carbon, low bulk density of $0.457/cm^3$, adsorptive capacity of 148.083mg/g of benzene, methylene blue adsorptive capacity of 941.247mg/g, ash content of 2.762% and yield of 45.16%. The XRF analysis showed that the elemental composition of the activated carbon produced varied, while the SEM analysis revealed that Bamboo activated carbon have better pore structure than that of Coconut and Palm Kernel Shell. The results revealed that bamboo activated carbon is better than coconut activated carbon and palm kernel activated carbon in effectiveness for adsorption processes. The result obtained from bamboo compared favourably with the commercial activated carbon than that obtained from coconut shell and palm kernel shell activated carbon activated at low activating agent concentration (Ademiluyi, Nwiador, & Akpa , 2017)

Fig. 45 Nigerian Palm Kernel Shell, Coconut and Bamboo used as adsorbents

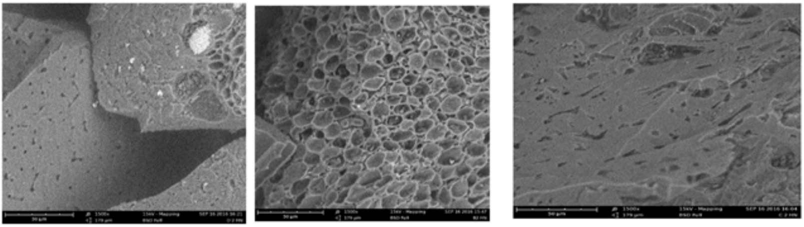

Fig 46 SEM of Palm Kernel Shell, Bamboo, Coconut shell Activated Carbons

5. Other Researches on Adsorption on the Use of Activated Carbons for Water Treatment. And Other Local Materials Supervised and Co-supervised By Me.

Aprioku Sydney Peter (2023) Diffusion Modeling and Adsorption of Crude Oil in Niger Delta Marine Environments Using **Plantain Peels and Leaves** *PhD Thesis* RSU, Port Harcourt

Noble Ezebuchi (2022) Removal of Organic Contaminants from Produced Water Using Activated Carbon Produced from Nigerian **Avocado Seeds** *PhD Thesis* RSU, Port Harcourt

Balogun Timothy (2022) Extraction and Characterization of Nigerian Allanblackia Floribunda Oil Seed Using Different Solvents for Biodiesel Production *PhD Thesis* RSU, Port Harcourt

Dune, Kingdom Kponanyie, (2021) Treatment of Oilfield Produced Water Using Activated Carbons from Elaeis Guineensis Biomass **(Palm oil waste Bunch)** for Reinjection. *PhD Thesis* RSU, Port Harcourt

Chikwendu N. B. (2022) Comparative Study on the Effect of Microwave and Chemical Activation on the Characterization of **Nigerian Bamboo** Activated Carbon. *M. Tech Dissertation* RSU, Port Harcourt

Ibegbu, G.B (2022) Treatment and Design of Treatment Plant of Ground Water from Sangotedo Ajah, Lagos using Activated Carbon from **Nigerian Bamboo**. *M. Tech Dissertation* RSU, Port Harcourt

Irem-Azodeh, Ugoese. (2022) Production and Rheological Modelling of Activated Carbon Toothpaste from **Nigerian Bamboo**, **Palm Kernel Shell and Coconut Shell**. *M. Tech Dissertation* RSU, Port Harcourt

Okon Ebi Ebi, **Ademiluyi Falilat Taiwo**, & Adepoju Tunde Folorunsho, (2018) Kinetic Modelling of the Biosorption of Methylene Blue onto **Wild Melon** (*Lagenaria sphaerica*), *American Journal of Chemical Engineering*. 6, 6, ,126-134.

6. **There are Ongoing Studies Presently by my Students also Using Local Materials:**

1. Maclayton, Nina Lolo (Ongoing) Performance Evaluation of Locally Produced Adsorbent from **Nigerian bamboo** for Treatment of Drinking Water in **Queenstown,** Opobo, Nigeria. *PhD Thesis* RSUST, Port Harcourt
2. Ateke Sukubo (Ongoing) Treatment of Drinking Water from **Kula Community** using Activated Carbon from Local Materials. IGEM, *PhD Thesis* RSUST, Port Harcourt.
3. Nwiador Nwibari (Ongoing) Modelling drying along dryer length using unfermented whole **cassava**. *PhD Thesis* RSUST, Port Harcourt
4. Nwankwoala Emmanuel (Ongoing) Modelling and Simulation of the Gasification of different **Bamboo**

Varieties for Energy generation. *PhD Thesis* RSUST, Port Harcourt.

5. Ayemobola Oluwaseun (Ongoing) Design of plant for production of biodiesel oil from **Allanblackia Floribunda Seed** *M. Tech Dissertation* RSU, Port Harcourt.
6. Ekom Idorenyin Inyang (Ongoing) Kinetics of Fatty acid removal from Palm kernel oil using **Nigerian Bamboo** Activated Carbon *M. Tech Dissertation* RSU, Port Harcourt.

7. Why Unit Operations Applications is Key to Nigerian Economic Growth

Vice Chancellor Sir, a look at the title of the inaugural lecture is the unique word Nigerian Economic Growth**.** Nigeria imports mainly: industrial supplies (27% of total in 2014), capital goods (23%), food and beverage (17%), fuel and lubricants (14%), transport equipment and parts (12%) and consumer goods (7%). 43% of total imports come from Asia; 34% from Europe; 15% from America and 7% from Africa (Tradingeconomics, 2022)

Our top five (5) items exported by Nigeria are listed in Table 25, removal of the first item (Mineral fuels including crude oil) leaves Nigeria with only 9.3% on Export, how will any economy of a nation grow on 9.3% export without effective applications of unit operations to convert our local materials to the form we can export them?,

Table 26 Nigeria's Top 5 Exports

S/No	Items Exported by Nigeria	Amount US$	Total exports %
1.	Mineral fuels including crude oil:	57.5 billion	90.7
2.	Fertilizers	1.9 billion	3
3.	Ships, boats	773.7 million	1.2
4.	Cocoa	679.8 million	1.1
5.	Oil seeds	398.2 million	0.6
6.	others	-	3.6

Source: Worldexports (2022)

Nigeria has the capacity to produce over 10 trillion litres of ethanol at a competitive price and earn trillions of naira exporting the product. Also, The President of the Nigeria Cassava Growers Association (NCGA) says that the **400 million litres of ethanol** that the country uses required only 100,000 hectares of farmlands from the 84 million hectares arable land in Nigeria (Vanguard . 2019). At the same time, we can earn several trillions of naira in foreign exchange from cassava products, the pharmaceutical industries across the world preferred cassava industrial starch to the corn starch being used for production of syrups. Nigeria uses 1.7 metric tonnes of industrial starch sold at N200, 000 per tonne amounting to N340 billion.

Also, we have what it takes to produce activated carbon from waste such as Bamboo, Palm Kernel Shell Coconut shells for internal use and export given the needed support from the government,

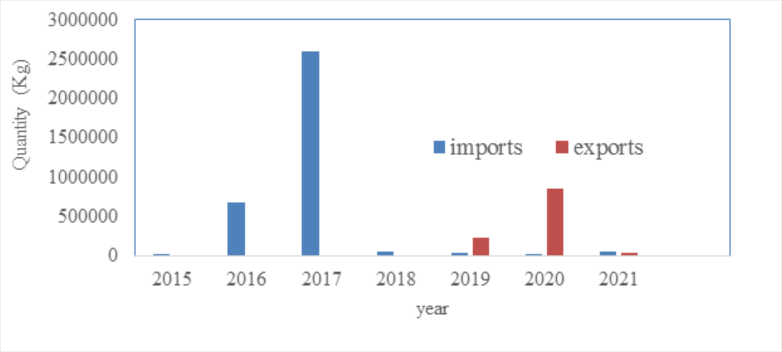

Fig 47 Nigerian Export and Import Data for Cassava Starch Source : Worldbank (2021)

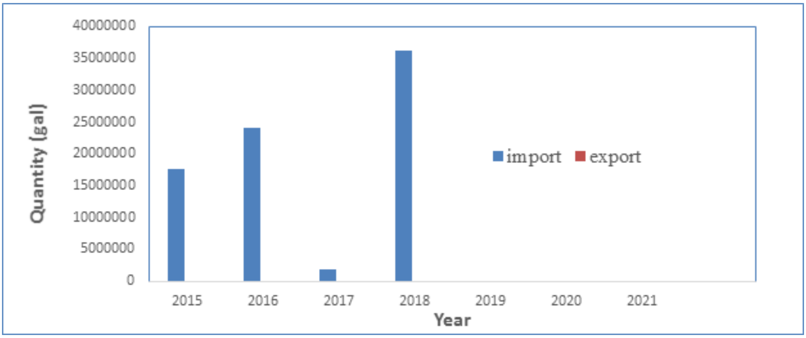

Fig 48 Nigerian Export and Import Data for Ethanol (Source: Worldbank , 2021)

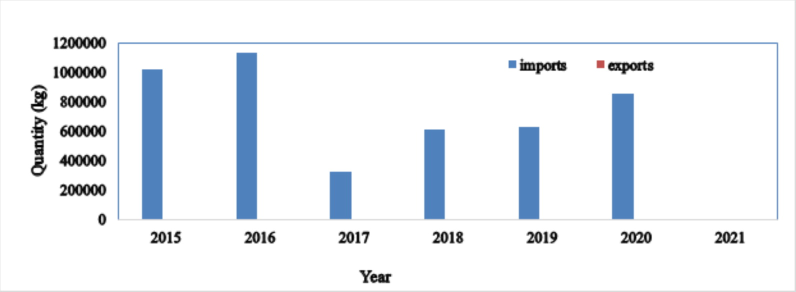

Fig 49 Nigerian Export and Import Data for Activated Carbon (Source: Worldbank , 2021)

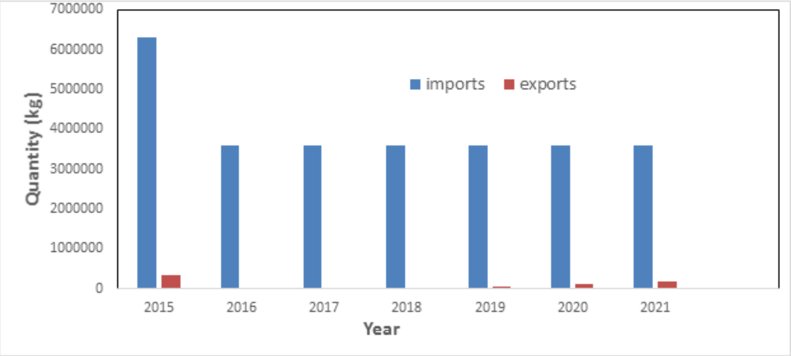

Fig 50 Nigerian Export and Import Data for Adhesives (Source: Worldbank , 2021)

8 My Other Productive Works

Vice Chancellor Sir, in 2015, I was on sabbatical at the Akwa Ibom University, Akpaden Akwa Ibom and worked as Acting, Head of Department of Chemical /Petrochemical Engineering (on Sabbatical, 2015 - Sept 2016.). I successfully graduated the first pioneering students of the Department. I successfully prepared all self-study forms for first Departmental accreditation, I met an empty unit operations laboratory, funds available was not enough to import hence I had to design, and construct equipment for the unit operations laboratory of the Department of Chemical /Petrochemical Engineering, Akwa Ibom State University within three months using available local materials, prepare manuals in-line with the equipment for the students to use, which made the Department to have first full NUC and COREN accreditation in 2016.

This equipment were all unit operations in Chemical Engineering some of which are shown in Figs 51-55.

Fig 51 Locally Constructed Filtration Unit

Fig 52 Locally Assembled Boiler and Constructed Heat Exchanger unit.

Fig 53 Locally Constructed Pyrolysis Reactor Unit

Fig 54 Locally Assembled Fixed Bed Adsorption Unit.

Fig 55 Locally Assembled Batch Evaporator, and Temperature Controller

9 Book Publications

Students see Chemical Engineering thermodynamics, Process dynamics, and Plant Design as a difficult course because of their wide applications and use of mathematics. The foreign books available in these courses are expensive and difficult to understand by students, and this has stirred me up to spend some years writing the books listed below. A lot of solved problems were added to make these courses easier for the students. I think am the first to publish such (Chemical Engineering Thermodynamics, Process Dynamics and Plant Design with Aspen hysys,) in the country in my field of study and some of the books are available in Rivers State University bookshop, Unilag bookshop, etc. at very cheap prices.

1) **Ademiluyi F. Taiwo** (2023) Introduction to Petrochemical Engineering, Chapter in a book CCMAS Handbook for Year 1 Students, Abuja, Nigerian University Commission (Accepted for publication in Press)

2) **Ademiluyi F. Taiwo** (2020) Environmental Pollution and Industrial Safety, Port Harcourt, Pearl Publishers.

3) **Ademiluyi F. Taiwo** (2018) Process Plant Design (WITH HYSYS), Port Harcourt, Pearl Publishers.

4) **Ademiluyi F. Taiwo** (2017) Fundamentals of Chemical Engineering Thermodynamics, Third Edition, Port Harcourt, Pearl Publishers.

5) **Ademiluyi Taiwo,** (2003) Process dynamics and

Control for Chemical Engineers, Port Harcourt, Pearl Publishers.

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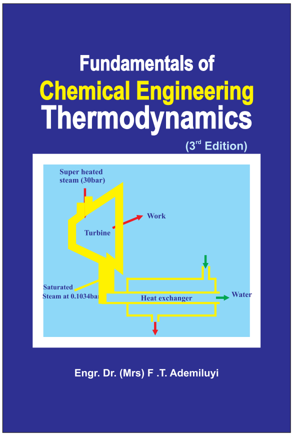
Fundamentals of
Chemical Engineering
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(3rd Edition)
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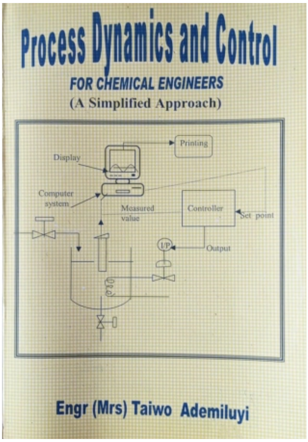
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(A Simplified Approach)
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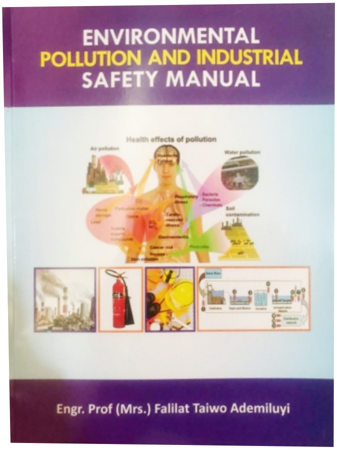
ENVIRONMENTAL
POLLUTION AND INDUSTRIAL
SAFETY MANUAL
Engr. Prof (Mrs.) Falilat Taiwo Ademiluyi

10 CONCLUSION

Vice Chancellor Sir, from my research, it has been established that there are Cassava cultivars that can be used that will not compete with the food chain for the production of Cassava flour, ethanol, adhesives, and other allied products. Also, Sir, because of the sensitive nature of cassava which gels quickly while drying, there is a need to predict the moisture ratio, drying rate, and heat transfer at different drying conditions especially when using a rotary dryer.

The same drying condition cannot be used for drying the ground cassava cultivars except they have close engineering properties. These properties and the models developed are necessary for cellular energy demand for the design of a rotary dryer for drying ground cassava. An empirical model that predicts the drying rate of ground cassava as a function of inlet air temperature and inlet air velocity in a rotary dryer has also been presented. The model had good agreement between empirical predictions and experimental data.

Empirical Models have also been presented that predict the specific heat transfer coefficient as a function of inlet air temperature and inlet air velocity and also the heat load as a function of inlet air temperature, inlet air velocity, and feed rate while drying ground Cassava in a rotary dryer. Predictions of the models were compared with experimental data and good agreement was obtained.

The new theoretical, Abowei-Ademiluyi model has been developed for predicting the drying kinetics of spherical particles in a rotary dryer at any known particle diameter, rotary drum diameter, and dryer length. The new model also accounts for the mass of feed which were not available before now.

Seven widely used thin-layer drying models and a newly proposed thin-layer drying model have also been applied to the drying of ground cassava, with the newly proposed model performing better than the existing models for all the drying conditions considered in the analysis.

The software developed is a useful tool for engineers, operators, and designers of rotary dryers for drying ground cassava which will foster the determination of heat load required for drying, determination of the diameter of dryer, length of dryer, design of number of flights, radial height of flight, the thickness of rotary shell, the thickness of insulation, air blower power, the power of the motor for feed drive, the power of motor to drive drum of dryer and the total heat resistance through the dryer. This software will enable the easy construction of small-scale rotary dryers for processing ground cassava for other uses and for export.

In order to produce a high yield of ethanol with good physical and electrical properties from whole cassava flour, cassava cultivars with high starch content, low protein content, and low dry matter should be used, while the cassava cultivars with moderate starch content (<50%), high protein and high fiber content can be used as food for human consumption and in food products.

Local starches modified with preservatives can be used as a substitute for imported samples to control viscosity and fluid loss in water-based drilling muds; Specific cassava cultivars with the highest amylase content and high-water absorption capacity produced drilling fluid with higher viscosity and lower fluid loss, which will not compete with the demand of cassava as food.

The research on Pyrolysis of waste sachets shows that the physical properties of the fuel oil produced compared favorably with that of Aviation fuel JP- 4, which shows that the fuel oil can be used in place of Aviation fuel JP -4. Pyrolysis of these waste sachets not only manages the environment but is also a means of cheaper energy sources for the aviation industry and other domestic fuel users. Wastewater sachets can be used to produce microcrystalline polyethylene wax of high quality with great economic potential.

Activated carbon produced from Nigerian-based waste bamboo is from a cheap source, which also, adds value to our economy and solves several adsorption problems in our environment and industry. It can be used for both liquid and gaseous phase purification since it has high bulk density, high pore volume, high porosity, high yield, high adsorptive content, and low ash content, low average particle size. The activated carbon from waste bamboo has been used to remove single metal ions from waste streams and in different metal recovery processes than Coconut and Palm Kernel Shells.

The research work on multiple adsorptions of different heavy metal ions in an aqueous solution using activated carbon from Nigerian Bamboo has also contributed to the search for less expensive and easily available material for the adsorption and separation process.

11 RECOMMENDATIONS

Vice-chancellor Sir, this inaugural lecture will not end without recommendations that will help actualize the development of our local materials from farm to factory and reduce dependence on imported products to develop our economy, hence Sir I would like to round up this lecture with the following recommendations:

a) Cassava processing factories should be established in all the local government areas of the states growing it to enable farmers to process them fast into dry flours or starches before sales.

b) Establishment of a Cassava board like the Cocoa board. The board should be ready to collect these dried products from the farmers, buy them off from them for export, or send them to biorefinery for ethanol production.

c) The import demand for ethanol is about 85% hence the need to establish biorefineries for ethanol from Cassava by the government in at least four regions of the country to meet the demand for ethanol in the country and even export ethanol.

d) Establishment of a local content development board by the Rivers State government whose functions would be to:

i . fund all research in these areas from farm to factory.

ii. carry out feasibility studies on the establishment of industry for products that are already developed and;

iii. recommend to the government where such factories will be established

e) Establishment of a center for local content development in our university with a well-equipped laboratory for such research. The center should develop a working relationship with the Nigerian Content Development Board (NCDB) to drive local content initiatives for economic development.

f) Constant synergy between the industry and the center for local content development in the university

g) The government at all levels should increase and continue the funding of research on local content development and sponsor the construction of unit operations for their processing into finished products.

h) Given the right environment, researchers who are involved in the development of local material for local use or export must be ready to give it all the commitment that it takes and not just carry out research for promotion's sake. After promotion to the rank of Professor, the research should continue until a product as good and standardized as the exported one is produced.

I) The development of local materials for local use or export needs researchers from different disciplines, we must be ready to work together as a team of researchers from various disciplines to develop our economy.

j) Our research should be problem-solving and not just giving students a research topic to get a degree, else we cannot develop our local materials from farm to factory.

Rivers State has all the local materials to develop this state, reduce unemployment, and export to other states and countries.

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